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JUNE, 1929

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Published monthly by the Optical Society of America in co-operation with the Association of Scientific Apparatus Makers of the United States of America. The Section on Optics is devoted to original papers on experimental, theoretical, and applied optics. The Section on Scientific Instruments is devoted to original papers on instruments of all kinds (electrical, mechanical, thermal, etc., as well as optical) for research, instruction, and industrial processes. Manuscripts for publication, are invited, whether authors are members of the Optical Society or not.

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Journal
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NEW YORK MEETING OF THE OPTICAL SOCIETY OF AMERICA

FEBRUARY 22–23, 1929

JOINT MEETING WITH THE AMERICAN PHYSICAL SOCIETY

A joint meeting of the Optical Society of America and the American Physical Society was held at Columbia University in New York City, February 22 and 23, 1929.

Notable features of this meeting were the invited addresses before the joint sessions of the two Societies (1) by Professor R. A. Millikan on "Cosmic Rays" given Friday afternoon and (2) by Professor H. B. Williams on "Some Physical Problems in the Field of Medicine."

Other papers which were of special interest and given by invitation before the Optical Society sessions were (1) "The Visual Acuity of the Bee" by Selig Hecht and Ernst Wolff of Columbia University and (2) "The Effects of Direct Stimulation of the Blind Spot" by Harry Helson of Bryn Mawr.

Abstracts of papers presented before the Optical Society at the various sessions are given in the following pages.

ABSTRACTS OF PAPERS

1. Deane B. Judd — **Bureau of Standards**

THE REDUCTION OF DATA ON MIXTURE OF COLOR STIMULI

It has long been recognized that an infinite number of sets of distribution curves, or visual response functions (of which Weaver's set of "elementary excitation curves" recommended by the Colorimetry Committee[1] of this society is one) can represent a given body of data on mixture of color stimuli. The author has previously found[2] by the method of least squares the best luminosity coefficients applying to one of these sets of distribution curves and has shown that these curves weighted by these coefficients sum to a good approximation to the luminosity function of the standard "neutral." It has now been demonstrated that there exist coefficients for any of the infinite number of sets of distribution curves which will make them sum to identically the same approximation to the luminosity. Hence it is now possible to use any of these sets for computing from the spectral energy distribution the dominant wave length, colorimetric purity, and brightness of a color stimulus. (As a practical demonstration, this computation has been carried out for four stimuli by means of five different sets of distribution curves.)

This study has resulted in the discovery of a set of distribution curves (one of the above 5 sets) which gives the same numerical results as the set of O.S.A. "elementary excitation curves" but which is more convenient for computation. The convenience of this set of curves is due to the fact that one of them is the *luminosity function itself*. On this account the luminosity coefficients are $L_r=0$, $L_g=1$, and $L_b=0$. The Tuckerman symmetrical formula for colorimetric purity,[3]

$$= \frac{3-\dfrac{1}{rL_r+gL_g+bL_b}}{3-\dfrac{1}{RL_r+GL_g+BL_b}}$$

becomes simply: $p=(3-1/g)/(3-1/G)$.

Bibliography:
1. Troland, J.O.S.A. & R.S.I., *6*, p. 548; 1922.
2. Judd, J.O.S.A. & R.S.I., *10*, p. 635; 1925.
3. Judd, J.O.S.A. & R.S.I., *13*, p. 135; 1926.

The present paper will appear in full in Bureau of Standards Journal of Research

2. K. S. Gibson—Raymond Davis **Bureau of Standards**

METHODS FOR DETERMINING THE COLOR OF SUNLIGHT AND DAYLIGHT

The Davis-Gibson filters [1,2,3,4,5] afford means of accurately determining the color of sunlight and daylight.

1. *Source at 2848°K.* Filters have been designed for precisely duplicating the colors of: (1) Sun outside atmosphere (equivalent to overcast sky[4] or sun plus blue sky), (2) Washington noon sun, June 21, (3) Washington noon sun, Dec. 21, (4) Washington mean noon sun,—all from Abbot's data of 1917. By adding Lovibond glasses of nominal grade from 0.0 to 1.0 and of known colorimetric values to the artificial sunlight or daylight, the color of the natural sunlight or daylight may be accurately determined. Data thus obtained in Sept. and Dec., 1928, will be illustrated.

2. *Source Varying from 2300°K. to 3000°K.* (Calibration of source may be made by means of Davis-Gibson filters.)[5] With filter (1), above, the color temperature will vary approximately from 4300°K to 7500°K, covering the range of daylight and noon sunlight. The color match with noon sunlight should be very close for all atmospheric conditions, the color of natural noon sunlight lying apparently between the black-body locus, which is relatively slightly purplish, and the colors given by filters (2), (3), and (4), above, which are relatively slightly greenish. Exact color match may be obtained by using Lovibond red glasses from 0.0 to 0.4.

3. *Source Varying from 2000°K to 3100°K.* The complete range of color temperature from 2000°K (or below) to 20,000°K may be covered by two filters:

(1) Source alone—2000°K (or below) to 3100°K.
(2) With first filter—approximately 2650°K to 5000°K.
(3) With second filter—approximately 4000°K to 20,000°K.

The deviations from black-body colors are very small, the colorimetric curves of the source and filter combinations crossing the black body curve at slight angles. These filters enable the complete range of color temperatures from the yellow of the setting sun to the blue of the sky to be measured. Lovibond red glasses may be used if exact match is desired.

The colorimetric characteristics of the filters will be illustrated. Measurements of intensity would also be possible, since the light transmissions of the filters are known.

Bibliography:
1. Davis & Gibson, J.O.S.A. & R.S.I., *14*, p. 135; Feb. 1927 (Abstract).
2. Phys. Rev. (2), *29*, p. 916; June, 1927 (Abstract).
3. J.O.S.A. & R.S.I., *16*, p 332; May, 1928 (Abstract).
4. Artificial Sunlight for Photographic Sensitometry, Trans. Soc. Motion Picture Engineers, *12*, pp. 225-236; 1928.
5. A Filter for Changing the Color Temperature of 2848°K to Average Daylight, B.S. Tech. News Bull. No 138, p. 143, Oct., and No. 139, p. 156, Nov. 1928.

3. Arthur R. Riddle **The Hegeman Memorial Research Laboratory, Metropolitan Life Insurance Company Sanatorium, Mount McGregor, New York.**

THE SHORT WAVE-LENGTH LIMIT IN SOLAR RADIATION, AS A FUNCTION OF TIME OF YEAR, AND TIME OF DAY

In light therapy, certain biological responses appear to come from stimuli of ultraviolet light of a very definite part of the spectrum. The region is found roughly to lie between 2900

and 3200 Angstroms. Since the solar spectrum does not cover all this, it seemed desirable to investigate the short wave-length limit, so far as might be permissible by spectrographic means. Spectrograms were made with a quartz spectrograph, the slit facing approximately south, towards a magnesium oxide reflecting surface, which received light from the north sky. Two sets of exposures were made, of all day duration, once a month, one for the brightest possible days, the other for the dullest—days usually quite overcast. Further sets of exposures were made for bright and dull days respectively, once each month, the spectrograph plate being changed every hour, from near sunrise to sunset. These results give approximately the short wave-length limit as a function of time of day. In the case of all day exposures, the short wave-length limit was—so far as light of this wave-length was able to produce a photographic image—as follows: for bright days, 303mμ in December, and 296mμ in June; for dull days, 305mμ in December, and 296mμ in June. These figures give extreme cases for shortest and longest days respectively, when measurements were possible. Space does not permit the inclusion of any readings, showing variation over the day, from sunrise to sunset. These will appear in the full paper.

The present paper will appear in full in J.O.S.A. & R.S.I.

4. W. T. Sproull and R. E. Martin — **Lehigh University**

IONIZATION AND THERMAL E.M.F. IN SELENIUM VAPOR

Selenium vapor was produced in a pyrex tube which had previously been evacuated. A potential difference of 240 volts was impressed between two electrodes sealed in the tube, a sensitive galvanometer being in series with the circuit. The tube was illuminated with visible light. After eliminating spurious effects it was found that intensities up to 3500 foot-candles caused no ionization sufficient to alter the conductivity of the vapor as much as ½%. X-rays carefully screened from the electrodes produced a marked ionization (5 to 40%). Using a quartz tube, it was found that ultraviolet light from a quartz mercury arc had no measurable effect. Only one strong mercury line (2537Å) falls below the photoelectric threshold for commercial metallic selenium (2670Å). These results do not appear to support the theory that light action in selenium is a modified photoelectric effect.

During these experiments, one of the spurious effects discovered was a thermal emf. in the selenium vapor. Keeping one electrode at 350°C, and varying the temperature of the other from 460° to 616°C, emf.-temperature curves were obtained for the saturated vapor, the emf. reaching to 0.58 volt. Thermal emf. in the pyrex was of course taken into account. Measurements could not be obtained with accuracy unless the vapor was saturated, or nearly so.

5. L. G. Hoxton — **University of Virginia**

A DIRECT-READING ENGINE FOR SPECTRA

The instrument described here has been built as an attachment to one of the regular dividing engines made by the Société Genevoise which happened to be the only one available. The purpose of the attachment is to enable one to obtain from the screw of the engine direct readings of either wavelengths or frequency-numbers from photographs taken either with a prism or a grating, without having recourse to computation. The adaptation to any particular case is made by the adjustment of a small number of moving parts. A preliminary trial of the method has been successful.[1]

The principle employed is that of projection, which is one of the ways of realizing bilinear transformations of which the Hartmann interpolation formula is a case. This principle has been used before, optically[2] and graphically,[3] for example. The method here is mechanical.

Bibliography:
1. L. G. Hoxton, Physical Review, *10*, p. 90; 1917.
2. E. S. King, Harv. Coll. Obs. Annals, *40*, p. 205.
3. F. Henroteau, Monthly Notices, Roy. Astr. Soc., *77*, p. 77.

6. R. V. Baud **Westinghouse Elec. & Mfg. Company**

FURTHER DEVELOPMENT IN PHOTO ELASTICITY

It has been customary in the past to machine the models used in photo-elastic work either of glass or celluloid and to use a compensator for measuring the difference $p-q$ between the principal stresses p and q, point by point.

In this paper a new method is outlined, consisting of using models made of a material of a large index of forced double refraction and of making photographs or drawings of the isochromatics of the loaded model and of a comparison strip in bending. By matching the colors of the model with those of the strip in bending a complete quantitative record of the shear-stress distribution throughout the model is obtained.

An example of the application of this new procedure is given for the case of a plate with a hole subjected to tension along one axis. Since the theory of elasticity offers an accurate solution for this particular case it can be used as a means of confirmation. The paper shows a very good agreement between analysis and experiment.

7. R. V. Baud **Westinghouse Elect. & Mfg. Company**

EXPERIMENTAL METHODS OF STUDYING STRESS DISTRIBUTIONS

The photo-elastic, strain measurement, analogy and Lueder's line methods of studying stress distributions are discussed in this paper. It is concluded that these methods make extensive use of optics and it is suggested that this interesting field be given some attention by the optical industry.

8. Selig Hecht and Ernst Wolf (By invitation) **Columbia University**

THE VISUAL ACUITY OF THE BEE

The characteristic response which bees make to a movement in their visual field furnishes a method for measuring their visual acuity. In this way it is found that the maximum visual acuity of the bee is lower than the lowest human visual acuity. Under similar maximal conditions human visual resolution is about 100 times that of the bee. The bee's eye is a mosaic of hexagonal pyramids of differing apical angle, which determines the separation of adjacent ommatidia. The minimum visual angle which the bee can discriminate as measured experimentally is identical with the minimum angular separation of adjacent ommatidia as found structurally. If this region of minimum ommatidial separation is painted out, the maximal visual acuity then corresponds to the angular separation of the remaining ommatidia.

The visual acuity of the bee varies with the illumination in much the same way that it does for the human eye. It is low at low illuminations; as the intensity of illumination increases it increases; and finally at high intensities it becomes constant. The resolving power of a structure like the bee's eye depends on the distance which separates the discrete receiving elements. The data then mean that at low illuminations the distance between receiving elements is large and that this distance decreases as the illumination increases. Since such a moving system cannot be true anatomically it must be interpreted functionally. It is therefore proposed that the threshold of the various ommatidia is not the same but that it varies as any other characteristic of a population. The visual acuity will then depend on the distance apart of those elements whose thresholds are such that they are functional at the particular illumination under investigation. Taking due consideration of the angular separation of ommatidia it is possible to derive a distribution curve for the thresholds of the ommatidia which resembles the usual probability curves, and which describes the data with complete fidelity.

The present paper will appear in full in Journal of General Physiology

9. **Edward Adams Richardson (Introduced by P. L. Bayley)** **Bethlehem, Pa.**

RELATIVITY VERSUS THEORIES OF LIGHT

The hypothesis that the velocity of light should be measured relative to the source, and the closely related hypotheses that the velocity of propagation of electrical and gravitational fields should be measured relative to the electrons and matter respectively, are considered.

This paper points out the importance of psychological considerations in the development of scientific points of view with special reference to the rise of Einstein's theory of relativity. It then proceeds to point out the application of the above hypothesis to Michelson and Morley's repetition of Fizeau's experiments on "aether drag" in moving refracting mediums, their later experiments on the velocity of the earth relative to the "aether," and Airy and Hoek's experiments on aberration, using telescopes filled with water and with air, and shows that such a hypothesis, satisfactorily correlates them. Next the time required for a light ray to travel between a source, moving with constant velocity, and the observer is determined for both the ether wave theory and the suggested hypothesis. The ratio of times, for the special case of nearest approach of the moving body, is that required by the Lorentz transformation.

From this point on, the paper is suggestive in character, pointing out the advantages of such a hypothesis from the standpoint of suggesting new lines of investigation. The theories of Einstein are regarded as mathematical processes for correcting the errors of an ether wave theory according to an arbitrary scheme which approximates more or less closely to the true mechanism, but have no physical, metaphysical, or philosophical importance from the standpoint of making time and space a four dimensional continuum of twisted space.

The unexpected result of Einstein's calculations regarding the precession of the perihelion of Mercury is interpreted as strongly supporting the view that gravitational potentials are propagated with the velocity of light relative to the gravitating body, hence must be closely related to electricity and light.

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Earth's Velocity Phil. Mag., *24*, p. 449; 1887.
Fizeau's Exper. Amer. Jour. of Sc. (3), *31*, p. 377; 1886.

10. Dr. Ludwig Silberstein **Kodak Research Laboratories**

ILLUMINATED SPACE-TIME: OPTICAL EFFECTS OF ISOTROPIC RADIATION SPREAD OVER ELLIPTIC SPACE

Einstein's gravitational field equations are integrated for the case in which the space is filled with isotropic radiation. This case is, naturally, of interest, since our space is actually traversed in all directions by radiation emitted from all stars, nebulas, etc. The complete solution of the problem is given and discussed for its implications, especially those relating to the Doppler effect.

The present paper will appear in full in Phil. Mag.

11. Herbert E. Ives **Bell Telephone Laboratories**

MOTION PICTURES IN RELIEF

This paper describes an extension of the idea of the parallax panoramagram recently described before the Society.* A special projection screen is used consisting of a translucent sheet in front of which and behind which are placed, with a small separation, opaque line gratings having opaque spaces much wider than the transparent. Upon this screen are projected simultaneously, from the rear, a large number of motion pictures from a wide range of directions. Each motion picture is thus broken up into narrow strips upon the screen and, according to the position of the observer on the viewing side, different pictures are seen. The motion picture films for projection are taken in a correspondingly large number of motion picture cameras, all directed from various positions at the same object. The number of different points of view and consequently the number of motion picture cameras and projectors should

be such that the cameras or projectors are practically in juxtaposition throughout the whole angle of view covered. Means are suggested by which the number of points of view may be multiplied by running the apparatus at high speed and securing several points of view for each ordinary frame projection period. The proposed method is unique among suggestions for projection of motion pictures in relief in that it calls for no viewing apparatus at the eyes of the observers. On the other hand, the apparatus for taking and projecting the pictures is cumbersome and costly.

* Journal of the Optical Society, December, 1928.
The present paper will appear in full in J.O.S.A. & R.S.I.

12. Harry Helson (By Invitation) **Bryn Mawr College**

THE EFFECTS OF DIRECT STIMULATION OF THE BLIND SPOT

Upon directly stimulating the optic disc by means of a light source exposed within the projection of the blind spot and of such size that the diameter of the image on the nerve head may be as small as 1/135 the diameter of the optic disc, all observers report a more or less diffuse light with a brighter core usually corresponding to the color of the stimulus. Exceptions to this rule will be discussed. If the observer is quick enough he can catch the form of the stimulus in the first moment of exposure after which details disappear. Adaptation occurs so rapidly that weak stimuli fade out soon after being seen. Two colors exposed either as rectangles side by side or as concentric rings within the blind spot can be seen simultaneously When the region surrounding the blind spot is stimulated so that most intense stimulation occurs at the boundaries of the blind spot, thereby fulfilling the conditions of the irradiation, gradient, and dispersion theories of vision in the blind spot, no bright central core is reported, often nothing is seen in the region of the optic disc. If stimuli fall in the center of the blind spot and around its edges, with proper adjustment of the intensity, observers report that between what is seen in the blind spot and immediately outside there is a dark interval, showing irradiation or diffusion does not reach in this case beyond the boundaries of the disc to adjoining sensitive retinal elements. Numerous experiments designed to test the irradiation, dispersion and diffusion theories will be reported. It is generally agreed that contrast effects, after-images and the like show that there is vision *in* the blind spot at times, but our experiments seem to show that there is vision *with* the optic disc. In the light of our experiments and until some more refined technique has demonstrated to the contrary the only possible interpretation we can give at present to our results is that they are due to direct stimulation of the optic nerve fibres with resulting sensations of light. We may say that when the optic nerve head is stimulated to a greater degree than the rest of the fundus light will be seen and that the "blind" spot under such conditions is not blind.

The present paper will appear in full in American Journal of Psychology, *41*, July, 1929.

ANNUAL REPORT OF THE SECRETARY OF THE OPTICAL SOCIETY OF AMERICA FOR THE CALENDAR YEAR 1928

Membership Tabulation

	Number of Members Dec. 31, 1928	Number of Members Jan. 1, 1929
Honorary	6	6
Regular, life	8	8
Regular, annual	303	320
Associate, individual	154	157
Associate, corporation	6	6
	477	497

Deductions—January 1, 1929

	Resignations	*Deaths*	*Transfers*
Regular, annual	6	1	0
Associate, individual	2	0	24

Additions—January 1, 1929

Regular, annual	24	Transferred to Regular Membership by action of Council, October, 31, 1928
Associate, individual	29	Elected to Associate Membership effective January 1, 1929

New Members Elected During Year

Geraldine Kline Walker, Research Associate for American Oil Chemists Society, Bureau of Standards, Washington, D. C.
Charles J. Huber, Director of Tech. Res-, Cheney Brothers, South Manchester, Conn.
Dean A. Lyon, Electrical Engineer, Phil-Suburban-Counties Gas & Electric Company, Norristown, Pa.
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Ernest A. Hutchinson, Director, L. A. School of Optometry, Los Angeles, Calif.
Warren W. Nicholas, Physicist, Bureau of Standards, Washington, D. C.
Horace C. Richards, Professor Mathematical Physics, University of Pennsylvania, Philadelphia, Pa.
Paul L. Bayley, Associate Professor of Physics, Lehigh University, Bethlehem, Pa.
Carleton C. Murdock, Asst. Professor of Physics, Cornell University, Ithaca, N. Y.

Resignations effective January 1, 1929:

P. S. Helmick, 1306—28th Street, Des Moines, Iowa
M. So, 1278 Omori, Araishiku, Tokyo, Japan
E. J. Wall, 38 Bromfield Street, Wallaston, Mass.
Charles E. St. John, Mount Wilson Observatory, Pasadena, Calif.
Frank Schlesinger, Yale University Observatory, New Haven, Conn.
John R. Freeman, 815 Grosvenor Bldg., Providence, R. I.
W. F. Boiler, Iowa City, Iowa
Henry Miller, Nela Research Laboratory, Cleveland, Ohio

Deaths

A. D. Cole, Ohio State University, Columbus, Ohio

Elected to Regular Membership by Action of the Council, October 31, 1928—Effective Jan. 1, 1929

J. W. Beams
F. G. Brickwedde
R. C. Gibbs
R. L. Hanson
E. A. Harrington
J. R. Harrison
H. J. Howard
H. D. Hubbard
E. O. Lawrence
H. W. Russell
H. F. Stimson
F. G. Wick (Miss)
A. W. McMahon
D. Stockbarger
W. F. Little
Wm. T. Anderson
Burt H. Carroll
W. H. Fulweiler
R. E. Martin
A. H Poetker
F. G. Slack
F. E. Swindells
T. R. Wilkins
F. M. Kannenstine

(*Signed*) CHARLES C. BIDWELL
Secretary

OPTICAL SOCIETY OF AMERICA

STATEMENT OF CASH RECEIPTS AND DISBURSEMENTS
For the Period from January 1, 1928 to December 31, 1928

CASH ON HAND, JANUARY 1, 1928		$ 9,380.34
RECEIPTS:		
Membership Dues	$3,341.47	
Subscriptions to the Support of Society	3,000.00	
Interest on Bank Balances	386.13	
Interest on Bonds	200.00	
Proceeds Optical Instruments Exhibit Washington Meeting	781.42	
Frederic Ives Medal Endowment	500.00	
Share of the Society in Journal Subscriptions	295.00	
Share of the Society from Advertisements in Journal	287.00	
Sale of Volumes I–V of Journal (Property of Society)	225.15	
Sale of Colorimetry Reports	9.95	
Total Receipts		9,026.12
Total Receipts, plus Cash on Hand January 1, 1928		$18,406.46

DISBURSEMENTS:

To Journal of the Optical Society of America and Review of Scientific Instruments, as per Contract with Association of Scientific Apparatus Makers of U.S.	$4,800.00	
Journal Subscriptions (97 at $3.00 each)	291.00	
Printing and Stationery	1.951.03	
Postage in Connection with Business of Society	89.53	
Postage on back numbers of Journal	7.87	
Travelling on Business of Society	20.06	
Clerical Expenses	64.00	
Advertising of Helmholtz's Physiological Optics	34.17	
Purchase of Liberty Bonds for Investment	5,026.56	
Purchase of Liberty Bond for Frederic Ives Medal Endowment Fund	504.10	
Accrued Interest on Bonds Purchased	41.14	
Fire Insurance on Volumes I–V of Journal	2.03	
Total Disbursements		$12,831.49
CASH ON HAND, DECEMBER 31, 1928		5,574.97
Total Disbursements, plus Cash on Hand, December 31, 1928		$18,406.46

INVESTMENTS:

$5000 Atchinson, Topeka, Santa Fe Gen. 4'S.
$5000 Fourth Liberty 4¼'S.
$ 500 Life Membership Fund
$ 500 Fourth Liberty 4¼'S. (Frederic Ives Medal Endowment Fund.)

I certify that the above report is correct to the best of my knowledge and belief.

ADOLPH LOMB, *Treasurer*
February 16th, 1929.

Adolph Lomb, Esq.,
Treasurer, Optical Society of America:

Dear Mr. Lomb:

In accordance with your request we have audited the treasurer's accounts of the Optical Society of America for the twelve months ending December 31, 1928; and we hereby certify that the treasurer's official report of receipts, disbursements and investments for the year 1928 is correct in every detail, as shown by bank statements, vouchers, etc.

Yours truly,
JAMES P. C. SOUTHALL
C. L. TRELEAVEN

JOURNAL OF THE OPTICAL SOCIETY OF AMERICA AND REVIEW OF SCIENTIFIC INSTRUMENTS

FINANCIAL REPORT FOR THE PERIOD OF JANUARY 1, 1928–DECEMBER 31, 1928

Receipts

Cash on hand January 1, 1928		$ 4,528.66
In account with the Optical Society of America		4,800.00
In account with the Association of Scientific Apparatus Makers of America—Advertising		7,943.15
Miscellaneous Receipts		
Subscriptions	$3,034.27	
Sale of back numbers	565.45	
Sale of Paper by F. Paschen	8.70	
Miscellaneous receipts, reimbursements, etc.	79.31	3,687.73
Total		$20,959.54

Disbursements

Printer	$8,058.40	
Salaries and Office Expenses	4,673.57	
Miscellaneous	67.06	$12,799.03
Cash on hand December 31, 1928		8,160.51
Total		$20,959.54

The above is a correct statement of accounts to the best of my knowledge and belief.

(*Signed*) F. K. RICHTMYER, *Business Manager*

We, the undersigned, duly appointed to audit the accounts of the Journal of the Optical Society of America and Review of Scientific Instruments at the close of business, December 31, 1928, hereby certify that we have examined the statement of receipts, and disbursements, the vouchers, check book and bank book and find them to agree with each other. We, therefore, certify that the above statement is a true statement of the accounts of the Journal of the Optical Society of America and Review of Scientific Instruments as of December 31, 1928.

(*Signed*) H. E. HOWE
H. R. CHILDS
R. C. GIBBS
Auditors

COMMITTEE ON OPTICAL INSTRUMENTS EXHIBIT

Michelson Meeting of the Optical Society of America
October 31–November 3, 1928

Financial Report

Total Receipts from Exhibitors		$850.00
Disbursements for postage, cuts, etc.	$ 68.58	
Remitted to Treasurer of Optical Society December 27, 1928, to apply on cost of Catalog of Exhibits of the Program of the Meeting	781.42	850.00

The foregoing report is respectfully presented to the Optical Society of America by the Undersigned committee.

(*Signed*) I. C. GARDNER, *Chairman*
G. H. VANEMAN
H. D. HUBBARD
R. DAVIS

December 26, 1928

We have looked over the accounts of the Committee on Optical Instruments Exhibit and find their financial statement to be correct. The number of pages of advertising in the catalogue at $15.00 per page check with the items in the receipts column. The disbursements are covered by receipted bills. The balance checks.

Respectfully submitted,
AUDITING COMMITTEE:
(*Signed*) C. G. PETERS, *Chairman*
A. Q. TOOL
L. B. TUCKERMAN

CLASSICAL SCATTERING IN X-RAY REFLECTION

By Paul Kirkpatrick

Sir J. J. Thomson's classical treatment of the scattering of short wave-length radiation by electrons shows that the scattered intensity from an unpolarized primary beam should vary as $(1+\cos^2 2\theta)$, where 2θ is the angle of deviation. This formula was appropriated by Darwin[1] and included in his formulation of the intensity of reflection of x-rays by crystals, and has been used in this connection ever since, being known as the "polarization factor."

Though the validity of the expression $(1+\cos^2 2\theta)$ as applied to scattering by substances not specifically crystalline has been investigated in numerous researches, no experimental test of the correctness of this factor for crystal reflection has heretofore been reported. Compton[2] measured the intensities of reflection of certain radiations in three orders and compared their ratios with those predicted by two equations, of which one did and one did not contain the polarization factor. The observations agreed much better with the equation which did contain the polarization factor, and this was taken to justify the factor's inclusion, but since both of the equations used were empirical the demonstration does not convince. The results of Mark and Szilard,[3] show that the polarization factor is substantially correct when θ has the special value 45°, but no data are known which apply to the smaller and more frequently used angles of reflection, and the confirmations obtained in the analogous field of non-crystalline scattering are not reassuring. For these reasons, and because of the continued use of the polarization factor in important measurements of the absolute intensity of crystal reflection, it would seem important to ascertain whether or not that type of scattering which constitutes crystal reflection may properly be treated in the classical manner.

The present writer designed and partially carried out an experiment to test this matter about a year ago. The work was interrupted after two angles of reflection had been examined, and since it now appears impossible to resume the measurements for at least two years it is deemed best to publish the results in hand, and at the same time bring the problem and a demonstrated mode of attack to the attention of other workers.

[1] Darwin, Phil. Mag., *27*, pp. 315 and 675; 1914.
[2] Compton, Phys. Rev., *7*, p. 658; 1916.
[3] Mark and Szilard, ZS. für Phys., *35*, Feb. 8, 1926.

APPARATUS AND METHODS

The reasoning employed in the deduction of the polarization factor also leads directly to the conclusion that when unpolarized radiation is incident upon a crystal the resulting reflected radiation will be polarized with its predominating electric vector normal to the plane of reflection, and in such degree that the ratio of mutually perpendicular electric vectors is $\cos^2 2\theta$. The polarization of such reflected beams has been measured by the use of the experimental arrangement shown in Fig. 1.

Radiation was produced by a medium-focus Universal Coolidge tube, mounted in the inclined position shown. A rock salt crystal 20 cm from the target reflected in high orders a combination of general and K

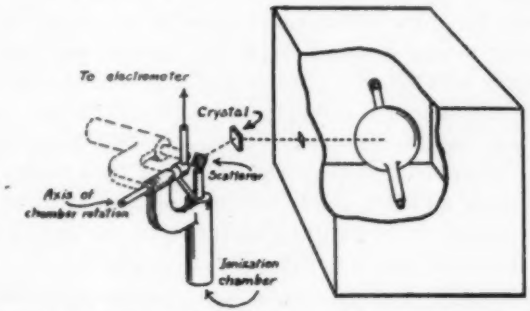

FIG. 1. *General arrangement of apparatus (not to scale) for measuring polarization of reflected x-radiation.*

characteristic radiation of tungsten at the desired angle in a horizontal plane of reflection. The reflected beam passed to a scatterer, placed about 10 cm from the crystal. A portion of the radiation scattered at ninety degrees by the scatterer entered an ionization chamber which was so mounted that it could be rotated about the reflected beam as axis. The polarization of this beam was determined from comparisons of the intensities scattered in horizontal and vertical directions at right angles to the beam.

The reflected beam, limited by stops to a height and width of one centimeter, impinged upon a scatterer consisting of a flat sheet of aluminum, ample in area to receive the entire reflected beam as limited by the stops. The scatterer was rigidly attached to the ionization chamber, so that it necessarily presented the same aspect to the chamber in all positions of the latter, and was inclined so that it made equal angles with the reflected beam and the direction of measured scattering.

A Compton electrometer was mounted near the axis of rotation of the chamber system, and provided with shielded electrical connections to the chamber so designed as to avoid capacitance changes upon relocation of the chamber. In order to eliminate from consideration the unknown polarization of the primary beam before reflection the x-ray tube was mounted with its axis inclined at forty-five degrees to the plane of reflection, as shown in Fig. 1. It is apparent from symmetry that the primary polarization, whatever its magnitude, can have no effect upon the ratio of scattered intensities in the direction of measurement.

THEORETICAL CONSIDERATIONS

The simple ratio of ionization chamber measurements in mutually perpendicular directions within a plane normal to a beam of x-rays is not necessarily a true measure of its polarization, as Compton and Hagenow[4] have pointed out. For a perfectly accurate polarization measurement it is required (1) that none of the radiation received in the measuring chamber shall have been scattered more than once; and (2) that this measured radiation shall have been deviated by the scatterer through an angle of just ninety degrees. If either of these conditions be violated the resulting ratio will be too high, that is, the radiation will seem to be less polarized than it really is.

It is obvious that multiple scattering decreases with diminishing thickness of the scatterer, and that it vanishes with an infinitely thin scattering plate. It was at first planned to measure polarization with scatterers of various thicknesses, and to accept as correct the extrapolation of these results to zero thickness. Investigation, however, showed no observable differences in the polarization ratios with scatterers ranging in thickness from .05 cm to .35 cm. It was therefore unnecessary to use the extrapolation method and scatterers about 3 mm in thickness were employed.

Inasmuch as the scattered beams were not ideally narrow, and since the extension of this investigation to large angles of reflection is limited solely by the difficulty of securing measurable amounts of radiation in the scattered beams, it becomes necessary to consider with some care the problem of the determination of polarization by the use of scattered beams of finite solid angle.

Let it first be considered that the beam from the crystal to the scatterer is parallel and of homogeneous cross-section as regards inten-

[4] Compton and Hagenow, J.O.S.A. & R.S.I., *8*, p. 487; 1924.

sity, and that it consists of two, superposed plane polarized components, A and B, the ratio of whose intensities is $B/A = P < 1$. Simple Thomsonian scattering will be assumed, since light weight scatterers are intended. As in Fig. 2, let H and K be two points, distant D cm, in the directions of the scattered radiation to be measured, from a small scatterer whose projected area perpendicular to the direction of measured scattering is dS. Let $1/D = a$. Points H and K will be spoken of as the poles of the scattered radiation. Imagine planes to be passed through H and K normal to the directions of scattering, as shown in the figure.

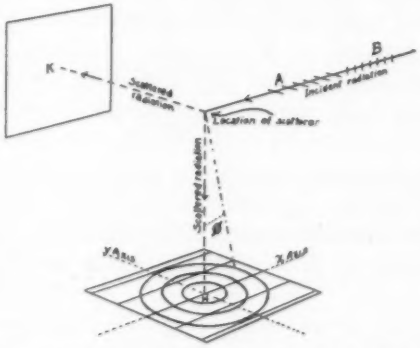

FIG. 2. *Diagrammatic representation of incident and scattered radiations, showing directions of electric vectors in the two components of the incident ray, and the loci of equal scattered intensities for each component. Circles on H plane represent loci of equal intensities from B component and parallel straight lines represent those of A component.*

The scattered intensity received upon either plane, for instance that about H, is made up of two parts, since both of the components, A and B, have contributed to it. We may draw upon the plane at H loci of equal scattered intensities from each of these two components. The resulting pattern is shown in Fig. 2. The loci from B will obviously be concentric circles, the intensity being zero at their center. The intensity on any circle, after Thomson's theory, is proportional to B and to $\sin^2 \phi$, where ϕ has the meaning conveyed in Fig. 2. The intensity loci of A radiation are, to a high degree of accuracy, a series of parallel straight lines. The intensity of A radiation at the pole H is proportional to dS, and may be called $J\,dS$. Then taking x and y axes in the plane, as shown in the figures, the total intensity at any point (x, y) takes the form

$$I_H = [\cos^2 ay + Pa^2(x^2+y^2)]J ds \qquad (1)$$

provided the point is sufficiently close to the pole for the approximation $\sin\phi=\phi$ to be permissible. Integrating this intensity over a square area of side t, situated on the H plane but not necessarily symmetrically with respect to the pole, we obtain the total power, E_H entering a square ionization chamber window thus situated. Noting (Fig. 3) that the

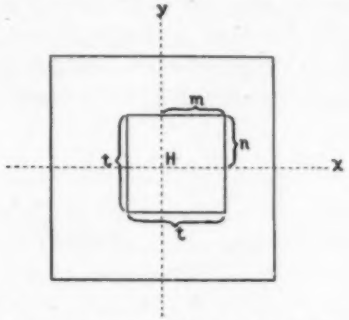

FIG. 3. *Relation of pole and axes of the H plane to ionization chamber window.*

coordinates of the pole with respect to the window center as origin are $(t/2-m)$ and $(t/2-n)$ this integration yields the following result:

$$E_H=\left[\frac{t^2}{2}+\frac{t}{2a}\sin an\cos an-\frac{t}{2a}\sin a(n-t)\cos a(n-t)\right.$$
$$\left.+\frac{Pa^2t}{3}[m^3-(m-t)^3]+\frac{Pa^2t}{3}[n^3-(n-t)^3]\right]Jds. \qquad (2)$$

It is now possible to dispense with the assumption that the scatterer is small. For present purposes it will be convenient and sufficient to assume a scatterer whose projection on the window coincides with the window itself. The total power, T_H, from this extended scatterer to the window is obtained by integrating E_H, the limits being taken so that the pole is carried over all parts of the window. Substituting $dm\,dn$ for dS and carrying out the operation one obtains

$$T_H=\int_{-t/2}^{t/2}\int_{-t/2}^{t/2}E_H=J\left[\frac{t^4}{2}+\frac{t^2}{4a^2}(\tan at\sin 2at)+\frac{Pa^2t^6}{3}\right]. \qquad (3)$$

Treating the radiation received at K in a similar way an analogous formula is obtained.

$$T_K=J\left[\frac{Pt^4}{2}+\frac{Pt^2}{4a^2}(\tan at\sin 2at)+\frac{a^2t^6}{3}\right]. \qquad (4)$$

The ratio of the intensities received at K and at H is $T_K/T_H=Q$, which is an experimentally observable quantity. This equation may be rearranged so as to read

$$P=\frac{4a^2t^3-6Qt-\frac{3Q}{a}\sin 2at}{4Qa^2t^3-6t-\frac{3}{a}\sin 2at}. \qquad (5)$$

This shows, first of all, that polarization may be measured with diverging scattered beams, and also, upon closer inspection, that the simple ratio of the intensities of such beams may in practical cases differ from P by a negligible amount. In the present work it may be shown that P never differs from Q by more than one third of one per cent. Since the errors were probably larger than this it is of little consequence whether the correction be applied or not. At larger angles of reflection, however, it would certainly be necessary to use equation (5), and at small angles it may serve as a guide in selecting the dimensions of apparatus. An analysis along similar lines has given assurance that the slight divergence of the reflected beam has no measurable effect upon the P values.

RESULTS

The solid curve of Fig. 4 shows the results to be expected upon the basis of the accepted polarization factor. I have investigated the polarization of reflected rays whose deviations were $2\theta=15°\ 08'$, and

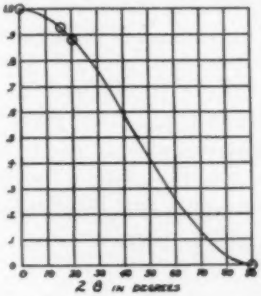

FIG. 4. *Comparison of theory and experiment. Solid curve is a plot of* $\cos^2 2\theta$, *which represents the classical expectations with respect to the polarization of reflected x-rays. Circles represent the observed or otherwise known polarizations.*

$2\theta=20°\ 10'$, and the results are represented by two of the circles in the figure. A point has also been circled at $2\theta=0°$, the correctness of

which may be deduced from considerations of symmetry, and the fourth point, at $2\theta = 90°$ has been obtained from the previously cited work of Mark and Szilard.

The investigations at the angles 15° 08′ and 20° 10′ each consisted of three determinations, all made on different days, each determination involving from ten to thirty measurements of scattered intensity in each of the two chamber positions. They may be summarized as follows:

Angle of deviation (2θ) of reflected ray	Observed polarization of reflected ray	Theoretical polarization of reflected ray
15° 08′	.932 ± .004	.932
20° 10′	.875 ± .005	.881

These data are too few to justify extended discussion, but it is seen that, so far as they go, they support the Thomson polarization factor and are in agreement with the conception of crystal reflection as a classical phenomenon, amenable to the principles of electromagnetic optics. The results also tend to justify the use of a rock salt crystal as analyzer for the measurement of primary x-ray polarization.[5] It is hoped that this work may be continued and extended to other angles and other crystals at some future time.

A considerable part of the apparatus used in this and related investigations was obtained through the generousity of the directors of the Queen's Hospital of Honolulu, and the Rumford Committee of the American Academy of Arts and Sciences. Especial thanks are due to Miss Margaret Dewar for assistance throughout the experimental part of this work.

DEPARTMENT OF PHYSICS,
UNIVERSITY OF HAWAII,
HONOLULU, T. H., JAN. 19, 1929.

[5] Kirkpatrick and Miyake, Bul. Amer. Phys. Soc., *3*, p. 8; Nov. 1928.

INSTRUMENT SECTION

AWARD OF PRIZE FOR 1928

From year to year the Scientific Apparatus Makers of America has offered a prize of two hundred and fifty dollars for the best paper on scientific instruments, other than optical, to be published in this Journal during each calendar year. The purpose of this prize has been to stimulate the development of new apparatus and methods of measurement. Each year a Committee on Award has been chosen from among the leading scientists of America.

The Committee for the award for 1928 consists of Professor P. I. Wold, Union College, Chairman; Dr. Saul Dushman of the General Electric Company at Schenectady and Professor L. W. McKeehan of Yale Univerity. The Committee has carefully considered a large number of eligible papers and has unanimously voted to award the prize for 1928 to Mr. N. E. Bonn, for his article on "An Improved Rosa Curve Tracer" appearing in the issue of September, 1928, pp. 207–223. The editors desire to congratulate Mr. Bonn on the receipt of this honor.

On behalf of the Scientific Apparatus Makers of America as well as on behalf of the Editorial Board of this Journal we wish to extend to the Committee on Award our sincere appreciation of the care with which they have made this selection.

Similar prizes have been awarded since and including 1925. The editors of the Journal wish to take this occasion to express to the Scientific Instrument Makers of America their keen appreciation of the importance of these prizes in stimulating fundamental research in instruments and methods. A similar prize is offered for 1929.

The following have been the recipient of prizes for the years indicated.

1925. Lloyd A. Jones, New Method of Photographic Spectrophotometry.

1926. Horatio B. Williams, The Einthoven String Galvanometer.

1927. E. L. Harrington, A New Type of Aspirator of High Efficiency.

1928. N. E. Bonn, An Improved Rosa Curve Tracer.

COMPENSATING ZERO SHUNT CIRCUIT

By Joseph Razek and Peter J. Mulder

The property of a three electrode vacuum tube of changing its plate current in response to variations of potential applied to its grid, has had many applications in the field of physical measurements.[1] If the mutual conductance of a tube is 1000 micromhos, a change of one volt on the grid changes the plate current by one milliampere. It is customary to read this change in some form of zero shunt circuit as shown in Fig. 1. In this circuit, the plate current passing through the plate resistor R_1, at one value of the grid voltage, causes a voltage

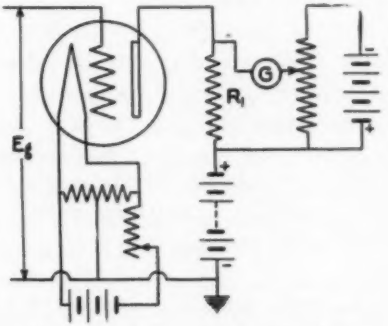

Fig. 1. *One form of zero shunt circuit.*

drop, which is balanced out by the potential divider and galvanometer. If the grid voltage changes, the plate current changes, which in turn changes the voltage drop across R_1, unbalancing the circuit and the galvanometer indicates a current proportional and approximately equal to the change in plate current.

Theoretically, an extremely high degree of voltage sensitivity might be obtained by the use of a sufficiently sensitive galvanometer. However, when efforts are made to use the circuit shown in Fig. 1 at high sensitivity, serious difficulties are encountered. The variations in the potentials of the several batteries in the circuit cause irregularities and drifts in the galvanometer far greater than those caused by the grid voltage change being measured.

The circuit can be improved considerably by the modification shown in Fig. 2, where both the plate of the tube and the balancing voltage

[1] Bazzoni, Jour. Frank. Inst., July, 1926. Harris, Jour. Sci. Instruments, May, 1928.

are supplied from the same potential divider.[2] It might reasonably be expected that the variations in the single battery now used will affect both the plate circuit and the balancing circuit similarly, leaving the galvanometer undisturbed, except in response to the variations of plate current caused by changes in grid voltage.

We shall now proceed to investigate this circuit mathematically in order to find out to what extent this expectation can be realized. In the circuit shown in Fig. 2, R_1 is a plate resistor, R_p is a resistance

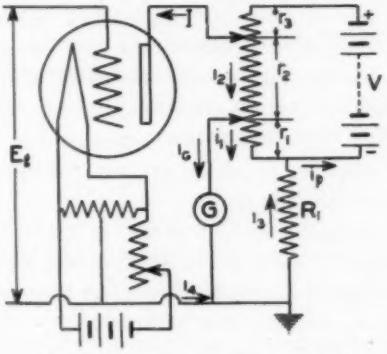

FIG. 2. *Compensating zero shunt circuit.*

across the battery V, used as a potential divider, from which both the plate voltage and the balancing voltage are tapped. Under a given grid voltage, E_g and a given plate voltage, a current I flows through the plate circuit, a potential E_p existing from the plate to filament of the tube. At a given setting r_1, a current i_G flows through the galvanometer which has a resistance R_G. Assuming current directions as shown by the arrows, application of Kirchhoff's Laws of electrical networks, leads readily to,

$$\left.\begin{aligned} i_1 &= i_p - I - i_G \\ i_2 &= i_p - I \\ i_3 &= I + i_G \\ i_4 &= I \end{aligned}\right\} \tag{1}$$

$$-V + i_p(r_1+r_2+r_3) - I(r_1+r_2) - i_G r_1 = 0 \tag{2}$$

$$E_p - i_p(r_1+r_2) + I(R_1+r_1+r_2) + i_G(R_1+r_1) = 0 \tag{3}$$

$$-i_p r_1 + I(R_1+r_1) + i_G(R_1+R_G+r_1) = 0. \tag{4}$$

[2] Wynn-Williams, Proc. Camb. Phil. Soc., *23*, P. 810; 1927.

Eliminating i_p from Eqs. (2), (3), and (4), and noting that $R_p = r_1 + r_2 + r_3$,

$$r_1[V + I(r_1+r_2) + i_G r_1] = R_p[I(R_1+r_1) + i_G(R_1+R_G+r_1)] \quad (5)$$

$$r_1[E_p + I(R_1+r_1+r_2) + i_G(R_1+r_1)] = (r_1+r_2)[I(R_1+r_1) + i_G(R_1+R_G+r_1)] \quad (6)$$

Let us now define the plate current of a vacuum tube by,[3]

$$I = AE_a + JE_p + GE_g \quad (7)$$

where

A = filament temperature function
J = plate to filament conductance
G = mutual conductance
E_a = filament voltage.

The three quantities A, J, and G are not constants, except where the characteristic curves are linear.

Eliminating E_p from Eq. (6) by means of Eq. (7), it is possible to eliminate I from Eqs. (5) and (6), thus obtaining, after ordinary algebraic reduction, an equation for the galvanometer current, i_G, involving E_g, V, the resistances, and the tube parameters.

$$i_G[J(R_1R_pR_G + R_1R_pr_2 + R_Gr_1r_3 + R_Gr_2r_3 + r_1r_2r_3 - R_1r_2^2) + R_1R_p + R_GR_p + r_1r_3 + r_1r_2] = Ki_G = -(AE_a + GE_g)(R_1R_p + r_1r_3) + V(r_1 - JR_1r_2) \quad (8)$$

The total derivative with respect to time is given by

$$\frac{di_G}{dt} = \left(\frac{\partial i_G}{\partial V}\right)\frac{dV}{dt} + \left(\frac{\partial i_G}{\partial E_a}\right)\frac{dE_a}{dt} + \left(\frac{\partial i_G}{\partial E_g}\right)\frac{dE_g}{dt} \quad (9)$$

where the time derivatives of V, E_a, and E_g are measures of the fluctuations in those quantities. The partial derivatives of Eq. (9) can be found by partially differentiating Eq. (8) with respect to the appropriate variable.

$$\frac{\partial i_G}{\partial V} = +\frac{1}{K}(r_1 - JR_1r_2) \quad (10)$$

$$\frac{\partial i_G}{\partial E_a} = -\frac{A}{K}(R_1R_p + r_1r_3) \quad (11)$$

$$\frac{\partial i_G}{\partial E_g} = -\frac{G}{K}(R_1R_p + r_1r_3). \quad (12)$$

[3] Van der Bijl, Thermionic Vacuum Tubes, p. 154.

For i_G to be independent of fluctuations in V, E_a, and E_g, the appropriate partial derivative must equal zero. To make the galvanometer current independent of variations in V, Eq. (10) must equal zero. This means that

$$r_1 = JR_1r_2 \quad \text{or} \quad r_1/r_2 = JR_1 \tag{13}$$

which might therefore be stated as the condition for compensation of plate battery variation. Further, since Eqs. (11) and (12), set equal to zero lead to values of the resistances equal to zero—an unattainable value in a practical circuit, the given circuit cannot be self compensating for variations in grid voltage or filament voltage.

In using the circuit, the resistances are so adjusted that at the initial grid voltage the galvanometer current is zero. Applying this condition, and the compensating condition of Eq. (13) to Eq. (8) reduces the latter to

$$AE_a + GE_g = 0. \tag{14}$$

Substituting Eq. (14) into Eq. (7), we have

$$I = JE_p. \tag{15}$$

Equation (15) shows that the circuit is compensating for fluctuations in the plate battery only when the tube acts as a pure ohmic resistance. The circuit is thus seen to be equivalent to a Wheatstone bridge, and the result obtained above might have been anticipated.

An expression for the sensitivity results upon differentiating Eq. (8) partially with respect to E_g. It is a little more convenient, however, to get the partial derivative, $\partial E_g/\partial i_G$ which after algebraic reduction is

$$\frac{\partial E_g}{\partial i_G} = -\left\{\frac{J}{G}(R_G + r_2) + \frac{1}{G} + \frac{Jr_3(R_Gr_3 - R_1r_2)}{G(R_1R_p + r_1r_3)} + \frac{(R_GR_p + r_1r_2)}{G(R_1R_p + r_1r_3)}\right\} \tag{16}$$

Equation (16) is an expression for the reciprocal of the sensitivity, or the voltage change on the grid to give unit change in the galvanometer current.

In the usual applications of the circuit, r_3 is zero, that is, the full potential of V is applied to the plate circuit of the tube. Making r_3 equal to zero, and introducing the compensating condition of Eq. (13) leads finally to a simplified expression for the reciprocal of the sensitivity,

$$\frac{\partial E_g}{\partial i_G} = -\frac{1}{G}\left[1 + \frac{R_G}{R_1}(JR_1 + 1) + \frac{r_1}{R_1}\right]. \tag{17}$$

We find experimentally that the sensitivity actually obtainable in this circuit is practically that predicted by Eq. (16). We find also that the compensation condition of Eq. (13) correctly indicates the adjustment for the maximum stability.

Equation (13) indicates that the circuit will be compensating for variations in the plate battery when the tube acts as an ohmic resistance. That is, the tube must be operated at a point at which the tangent to the plate voltage-plate current curve passes through the origin. Fig. 3 shows a group of characteristic curves obtained for a *CX-312A* tube, with sections of the tangents, passing through the origin indicated. In order that the bend in the curve may not come at too high voltage,

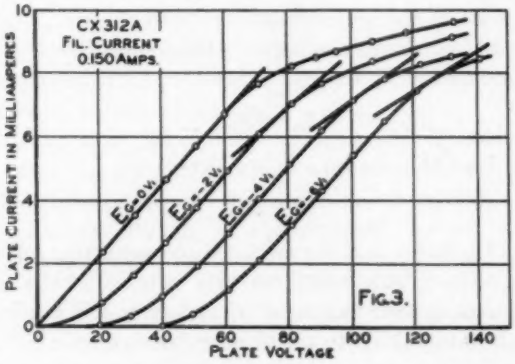

FIG. 3. *Plate current—plate voltage characteristic curves showing operating points for compensation at various grid voltages.*

it is necessary to operate the tube at a reduced filament current. Also, since the desirable operating points are near saturation, the proper grid bias must be chosen to make the value of the mutual conductance as high as possible. This is necessary since Eq. (16) shows that the sensitivity of the circuit depends directly on the value of the mutual conductance.

On setting up the circuit, it was found that the stability was considerably better when the tube was operated at the point chosen as described in the last paragraph. The value of sensitivity found experimentally by applying a known voltage change to the grid, and noting the corresponding galvanometer current, checked with the sensitivity predicted by Eq. (16), to about 1%. A sensitivity of 6000 mm per volt was obtained with easily usable stability.

This circuit is not as sensitive for a given stability as a more elaborate circuit using two tubes, but for many purposes where great sensitivity is unnecessary, the simplicity attained by using a single tube is a definite advantage. This circuit has been used for measuring photoelectric currents, by impressing the voltage drop caused by the photoelectric current through a resistor, across the grid and filament of the tube.

RANDAL MORGAN LABORATORY OF PHYSICS,
UNIVERSITY OF PENNSYLVANIA, PHILADELPHIA, PA.,
FEB. 12, 1929.

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Volume V of this series of Critical Tables follows the general plan of previous volumes, now so well known as to render unnecessary comment as to scope and purpose. The subjects covered are: Viscosity and Fluidity; Kinetics of Physical Processes; Heat Capacity; Mechanical Equivalent of Heat; Thermal Effects accompanying Physical and Chemical Processes; Thermal Conductivity; Radiometry; Spectroscopy; Photometry; Mechanical Equivalent of Light; Photography; Properties of Soaps and their Aqueous Solutions.

A detailed summary of the contents of each section is quite beyond the scope of a brief review. In the extensive section on Spectroscopy, for example, (160 pages) are found: tables of secondary and tertiary standard lines; emission and absorption spectra (excluding x-rays); solar and stellar spectra (including tables of unidentified lines); luminescence and fluorescence; spectral series data (optical term values for the elements); band spectra; Zeeman effect, etc. The section on Radiometry covers: radiation constants; black body radiation, total and monochromatic; emissivity of selected substances; optical constants of elements and various substances; filters (for radiometry and photometry); mechanical equivalent of light.

An index to the first five volumes is included at the end of volume V.

F. K. RICHTMYER

HIGH GRID RESISTOR AMPLIFIER

By Peter J. Mulder and Joseph Razek

In the course of the development of a vacuum tube amplifier for use in a photoelectric spectrophotometer, we have been led to examine the characteristics of the thermionic tubes, especially with reference to changes brought about by variations in the attached circuits. The change caused by the insertion of resistance into the plate circuit is well known,[1,2] as is also that caused by the addition of resistance into the grid circuit.[3]

The alteration in the "*C*"-battery voltage-plate current characteristic for a *CX*-312*A* tube, caused by introducing resistance into the grid

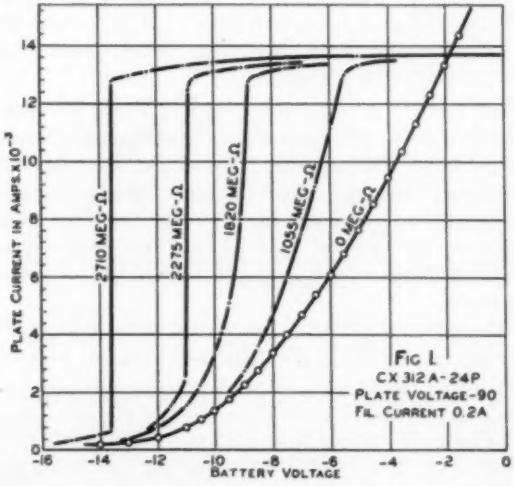


Fig. 1. *Relation between plate current and C bias battery voltage for various values of grid resistor.*

circuit is shown in Fig. 1. The curve indicated with circles is the normal grid voltage-plate current characteristic. The other curves show the effect of introducing various resistances, between the grid of the tube and the "*C*" bias battery. The last curve, with 2710 megohms inserted, has a very steep portion, a plate current change of twelve milliamperes occurring for a change of one tenth volt biasing potential.

[1] Van der Bijl, "Thermionic Vacuum Tubes," p. 169.
[2] Morecroft, "Principles of Radio Communication," p. 902.
[3] Von Ardenne, Popular Radio, Jan., 1928.

Unfortunately, at this extreme value of grid resistance, the curve followed by the plate current with a change in the grid potential, does not repeat if the change is made in the reverse direction.[4] For the particular tube used, grid resistors up to 1800 megohms could be used with assurance that the curves obtained would be independent of the direction of the grid biasing voltage change.

Great difficulty was encountered in obtaining constant resistances of the high values used, until Dr. C. B. Bazzoni of our department, suggested the use of xylol and alcohol. Pure xylol is practically a perfect insulator, up to at least two hundred volts, but by the addition of small quantities of alcohol the conductivity may be given any desired value over a wide range. The mixtures were sealed into glass tubes provided with sealed-in contacts. These resistors were found to vary considerably immediately after making, but when equilibrium conditions had been reached, they remained constant over periods of months. For lower values of resistance, pure glycerine has also been used.

The explanation of the shape of the curves shown in Fig. 1, lies in the grid currents. The flat portions to the right of the normal characteristic, where the grid is only slightly negative, are due to the current of electrons picked up by the grid. The parts on the other side of the normal characteristic are caused by current in the opposite direction. Here the grid is more negative and the current is predominatingly or entirely due to the positive ions collected by the grid. This change in characteristic together with the reversal in the direction of the grid current is not new.[5] Von Ardenne published somewhat similar curves,[6] but the degree of the change was not very large, being just noticeable in his curves. The large variation here shown results from the very high resistance used, and is progressively greater with the resistance.

Assuming that the current of positive ions picked up by the grid when it is negative arises from collisions between electrons and neutral atoms or molecules, it is not unreasonable to suppose that there might be a proportionality between the grid positive ion current and the plate electron current. That such is the case is shown by Fig. 2, the curve being essentially straight for plate currents less than thirteen milliamperes. At that point, the grid begins to be positive with respect to some points of the filament, and it attracts some negative electrons.

[4] Carwile, Phys. Rev., p. 284, Paper No. 31, Feb., 1929.
[5] Morecroft, "Principles of Radio Communication," p. 477.
[6] Von Ardenne. Reference No. 3.

Increasing the plate current by making the grid more positive, causes more electrons to be attracted to it, and at reversal the positive ion current and the negative electron current are equal. For still higher plate currents, the latter predominates. Moreover, the addition of various high resistances into the grid circuit does not affect the proportionality between the positive ion grid current and the plate current. We have obtained the identical curve with values of the grid resistor up to two thousand megohms. This means that however the

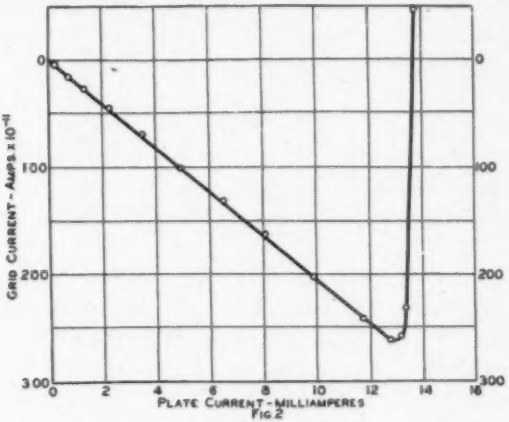


FIG. 2. *Relation between grid current and plate current.*

plate current may depend on the tube parameters, the grid positive ion current depends on the same parameters in the same way, except for the constant of proportionality, which we shall indicate by "k." The slope of the grid current-plate current curve was found to depend slightly on the point of the filament to which the plate return was made.

With no resistances in circuit, the plate current of a vacuum tube may be represented by[7]

$$i_p = AE_A + JE_B + GE_C$$

where

E_A = filament voltage
E_B = plate battery voltage
E_c = grid biasing voltage
A = filament temperature function
J = plate conductance of tube
G = mutual conductance of tube
R_1 = resistance in series with plate of tube
R_2 = resistance in series with grid of tube

[7] Van der Bijl, "Thermionic Vacuum tubes," p. 154.

The quantities, A, J, and G, need not be constant over the whole characteristic curve.

Reference to Fig. 2, shows that the positive ion grid current, i_s is linearly related to the plate current, i_p, therefore,

$$i_s = k i_p. \tag{1}$$

Hence, when resistances are introduced into the plate and grid circuits, the equation for the plate current may be written,

$$i_p = A E_A + J(E_B - R_1 i_p) + G(E_c + R_h k i_p). \tag{2}$$

Simplifying this expression gives an equation for the plate current of a tube in a circuit,

$$i_p = \frac{A E_A + J E_B + G E_c}{1 + J R_1 - R_h k G} \tag{2a}$$

from which

$$G' = \frac{\partial i_p}{\partial E_c} = \frac{G}{1 + J R_1 - R_h k G} \tag{3}$$

$$J' = \frac{\partial i_p}{\partial E_B} = \frac{J}{1 + J R_1 - R_h k G} \tag{4}$$

$$A' = \frac{\partial i_p}{\partial E_A} = \frac{A}{1 + J R_1 - R_h k G}. \tag{5}$$

These equations show that the addition of a resistance into the plate circuit of a tube reduces the slope of all its characteristic curves, while

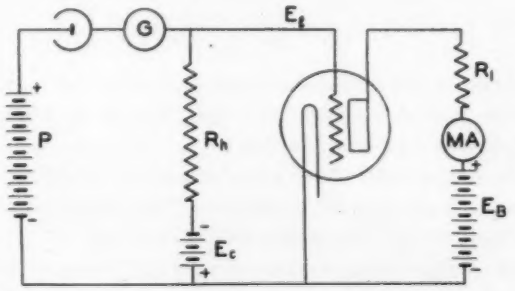


FIG. 3. *High grid resistor amplifier adapted for measuring photoelectric currents.*

resistance introduced into the grid circuit makes the slope of each characteristic greater, as long as positive ion grid current flows. We have obtained experimental verification of these equations. It is shown

by Eq. (3) that for suitable values of the grid resistor R_h, the effective value of the mutual conductance, G', may become very large. When so used, the tube can give high amplification.

We have used a tube in this manner for the amplification of photoelectric currents. Vacuum tubes have been used for this purpose by numerous experimenters.[8] In our experiments, the circuit was arranged as in Fig. 3. A sensitive galvanometer (2×10^{-11} amp/mm) is inserted in series with the photoelectric cell to read the photoelectric current directly, and a milliammeter is added into the plate circuit to indicate the corresponding plate current changes. By this method current amplifications of more than 2×10^{7} have been measured, using a single tube.

For the purpose of determining the sensitivity of the circuit as a function of the tube constants and the constants of the circuit, the equation for the sensitivity will be derived. For this analysis, the equivalent grid circuit may be represented as in Fig. 4.

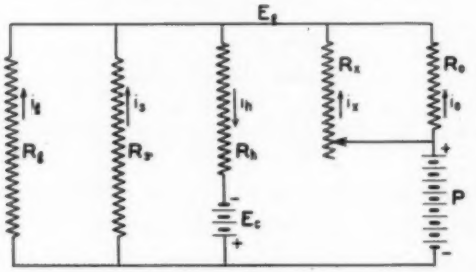


FIG. 4. *Equivalent grid circuit for Fig. 3.*

If, in addition to the symbols already defined, we let

R_g = grid to ground resistance over the parts of the tube

R_s = grid to ground space resistance

R_0 = cathode to ground resistance over parts of photoelectric cell

R_x = cathode to anode space resistance of photoelectric cell

P = photoelectric cell energizing battery voltage.

The currents in the various resistances are indicated by "i" with the corresponding subscript. Since E_g, the grid potential, is generally negative with respect to the ground, currents flow as indicated.

By application of Kirchhoff's Laws of Electrical Networks, the following equations are readily obtained.

[8] Ferrie, Jonaust and Mesny, Proc. I.R.E., Aug., 1925, and references there cited.

$$i_x = i_h - i_g - i_s - i_0 \tag{6}$$

$$i_h = (E_g + E_c)/R_h \tag{7}$$

$$i_g = -E_g/R_g \tag{8}$$

$$i_0 = (P - E_g)/R_0. \tag{9}$$

as shown by Fig. 2,

$$i_s = k i_p. \tag{10}$$

Substituting, Eqs. (7), (8), (9), and (10) into Eq. (6) gives,

$$i_x = E_g/R_h + E_c/R_h + E_g/R_g - k i_p - P/R_0 + E_g/R_0. \tag{11}$$

Differentiating Eq. (11) partially with respect to i_p, and noting that E_c and P are constant, leads to

$$\frac{\partial i_x}{\partial i_p} = \frac{\partial E_g}{\partial i_p}\left(\frac{1}{R_h} + \frac{1}{R_g} + \frac{1}{R_0}\right) - k. \tag{12}$$

Since $\partial i_p/\partial E_g = G$, this may be simplified into

$$\frac{\partial i_p}{\partial i_x} = \frac{GR_h}{1 + \frac{R_h}{R_g} + \frac{R_h}{R_0} - R_h k G}. \tag{13}$$

When a resistance is introduced into the plate circuit, the effective mutual conductance becomes, $G' = G/(1 + JR_1)$. Introducing this into Eq. (13), gives for the sensitivity

$$\frac{\partial i_p}{\partial i_x} = \frac{GR_h}{(1 + JR_1)\left(1 + \frac{R_h}{R_g} + \frac{R_h}{R_0}\right) - R_h k G} \tag{14}$$

Eq. (14) can also be interpreted as the ratio of the change in plate current resulting from a change in the photoelectric current, to the photoelectric current change itself. This equation may be compared with Eq. (3), when ∂E_c is replaced by $R_h \partial i_x$. The additional terms in the denominator of Eq. (14) come from considering the leakage resistances of both the vacuum tube and the photoelectric cell, and show that the circuit can be used with ordinary tubes, provided that the leakage resistances are fairly large compared to the grid resistor it is desired to use.

We have found that in some tubes the leakage over the bakelite base is excessive and variable, and in such cases, the grid connection must be insulated from the base. This can be done by drilling around the grid prong until it can be broken loose from the base. After thor-

oughly cleaning the press of the tube, molten sulfur is poured into the press, which on cooling effectively supports and insulates the grid prong. The socket grid connection must also be removed, and contact to the grid prong made directly by means of a copper tube.

Eq. (14) shows the advantage of operating the circuit with the grid sufficiently negative so that only positive ion grid current flows. If the grid is not sufficiently negative, the grid current reverses direction and the ratio of the grid current to the plate current becomes very much larger, as shown in Fig. 2. These two facts operate together to diminish the sensitivity materially.

The factor of proportionality between the grid positive ion current and the plate current, "k," is connected with the amount of residual gas present in the tube, which slowly changes over long periods of time. Therefore to obtain the same sensitivity after a considerable lapse of time, a correspondingly different value of the grid resistor must be used.

When a circuit similar to Fig. 3, is to be used in cases where the change in the photoelectric current is too slight to cause a change in the plate current which can easily be read on the plate milliammeter some form of zero shunt or vacuum tube bridge must be used.[9] In such a circuit the constant plate current is balanced out, leaving only the change in plate current to be read on an instrument more sensitive than the plate milliammeter.

CONCLUSION

Although the use of a grid resistor in an amplifying circuit is not new, it must nevertheless be noted that the high value of resistor here used makes an important alteration in the operation of the circuit, leading to decidedly improved results. For high amplification with a minimum of apparatus, the circuits suggested seem highly suitable. Furthermore, by taking cognizance of the positive ion grid current, it is possible to determine the limitations of a resistance coupled direct current amplifier, and to determine under what conditions the circuit can be made to give reproducible results, checking with predicted values.

RANDAL MORGAN LABORATORY,
UNIVERSITY of PENNA.
Mar. 1, 1929

[9] Razek and Mulder, J.O.S.A., & R.S.I. *18*, p. 460, 1929, and references there cited.

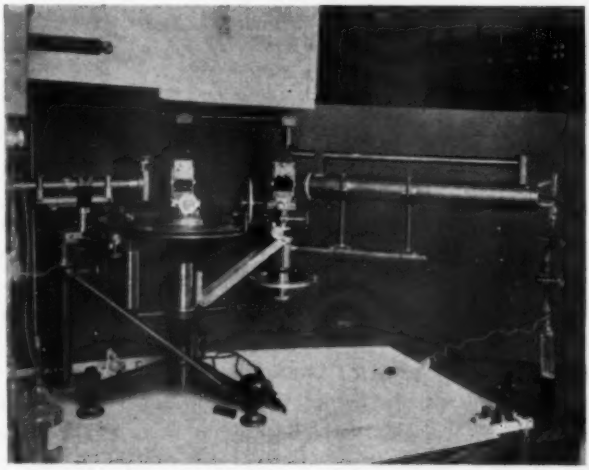
DESIGN OF A DOUBLE X-RAY SPECTROMETER

By J. H. Williams and S. K. Allison

INTRODUCTION

The term "double x-ray spectrometer," since the work of Bergen Davis and his associates, has come to mean an x-ray spectrometer in which reflection takes place from two crystals.

A spectrometer with two crystals was used in 1921 by Davis and Stempel,[1] the two crystals being placed so that their reflecting surfaces were parallel. Ehrenberg and Mark[2] were the first to devise a double spectrometer to study the width of x-ray spectrum lines. Their methods



Photograph of double x-ray spectrometer.

and apparatus were developed and applied to various problems in x-ray spectroscopy by Bergen Davis and his associates.[3] The mathematical theory of the instrument has been given by M. M. Schwarzchild.[4]

[1] Davis and Stempel, Phys. Rev., *17*, p. 608; 1921.

[2] Ehrenberg and Mark, ZS. für Physik, *42*, p. 807; 1927.

[3] Davis and Purks, Proc. N. A. S., *13*, p. 419; 1927. Davis and Purks, Proc. N. A. S., *14*, p. 172; 1928. Davis and Purks, Phys. Rev., *32*, p. 336; 1928. Davis and Mitchell, Phys. Rev. *32*, p. 331; 1928.

[4] M. M. Schwarzchild, Phys. Rev., *32*, p. 162; 1928.

The double x-ray spectrometer has a great resolving power due to the following conditions: 1. The angular width of a spectrum line reflected from crystal B, (the second crystal, when it is in the anti-parallel position to crystal A, the first crystal) is independent of the horizontal width of the slit. Hence large intensities may be obtained as contrasted to a single spectrometer. Roughly speaking, the angular range in which a spectrum line may be reflected from crystal B, in the position specified above depends on two factors: (a) the angular range through which a strictly monochromatic line would be reflected from a crystal and, (b) the angular range due to the intrinsic width of the spectrum line itself. In many cases the angular width of a line from crystal B has been shown to be considerably less than a minute of arc.[3]

2. If n_A is the order in which the crystal A is reflecting; n_B the order in which crystal B is reflecting; and $d\theta$ is the angular separation observed on crystal B for two wave lengths whose angular separation in the first order reflection from a single crystal is $d\alpha$, then it is easily seen that

$$d\theta = (n_A + n_B)d\alpha$$

which shows that even if A and B are reflecting in the first order the dispersion is twice that of a single spectrometer in the first order.

We have recently constructed in the shops of the University of California a spectrometer of the above type and, owing to the importance of Repetition the instrument in x-ray spectroscopy, we believe a description of the design is worth while. In the construction of this instrument we have received great assistance from Professor Bergen Davis of Columbia University who very kindly sent us sketches of the double spectrometer now in use in his laboratory. Certain features of our instrument to be described, such as the mountings of the crystals and the mechanism for moving crystal B through small angles, have been taken directly from the sketches sent us by Professor Davis. Several features of the instrument were designed by Mr. William Stamper and Mr. Otto Kaehler, mechanicians of the department.

GENERAL DESIGN

A good optical spectrometer forms the basis of the instrument. The collimator holder supports our slits. Crystal A is placed on the center of the spectrometer table and its orientation can be read to an accuracy of 10 seconds of arc on the main scale S_A by means of the vernier V_A. The telescope carriage of the original instrument, which rotates about the main axis, carries the axis of crystal B. Crystal B is thus free to rotate about the axis of crystal A and also about this second axis.

The rotation about the axis of crystal A is read on the main scale S_A with the vernier V_M to the above accuracy, and about its own axis is read to an accuracy of one minute of arc by means of a separate graduated scale S_B and vernier V_B. This feature makes it possible to set crystal B with approximately the correct orientation for any given spectral line, so that the line can be located with the minimum of searching. This is a special feature of the apparatus and this axis is shown in detail in Fig. 3.

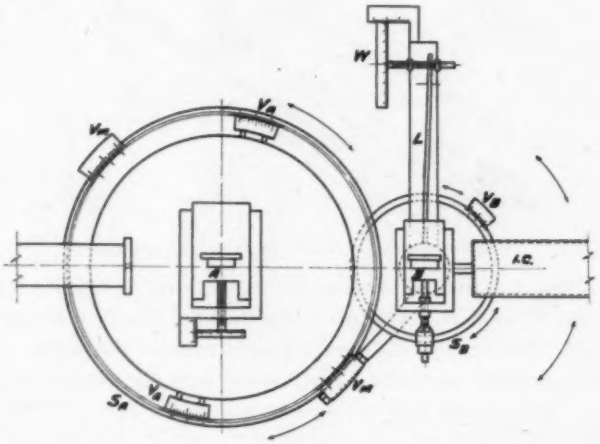


FIG. 1. *General plan of double x-ray spectrometer.*

THE SLIT SYSTEM

Since the width of the slits can be relatively large, as shown by Davis and Purks,[3] the slit system can be of any convenient design. Our slits are mounted on a brass tube 3 cm in diameter and 35 cm long. The ends of the tube are machined off at right angles to its long axis and as the slits fit tightly up to the ends the adjustment for parallelism is automatically effected. Set screws fix the slits to the tube and the slits may be rotated until vertical. The tube is held in two brass jaws 1.5 cm thick. These jaws can be rotated about a vertical axis so that the beam is directed to the face of crystal A. By means of a screw and movable wedge the horizontal width of the slits can be adjusted to give the maximum resolving power. There is no provision for limiting the vertical height of the slits but this can be easily done by placing lead vanes of variable width in the path of the beam.

CRYSTAL MOUNTINGS

The design of the mountings is seen in Fig. 2.

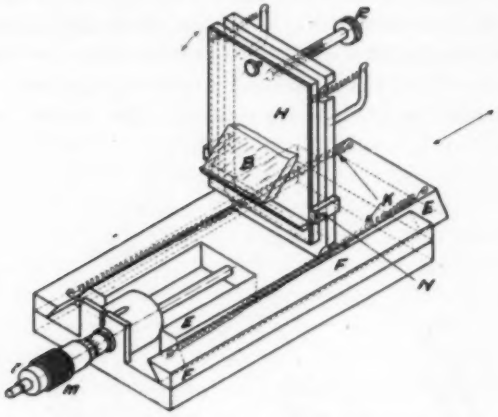


FIG. 2. *Mounting of crystals on double x-ray spectrometer*

The screw R allows the crystal holder H to be tilted over its hinged connection N so that a vertical adjustment of the face of the crystal is secured. Springs keep the holder tight against the screw. A screw and wheel permits crystal A to be moved over the center of the spectrometer table, as the base is constructed in two parts, F fixed, and E moveable. E is kept pressed against the screw by the springs K. For crystal B we have a micrometer head M, graduated to read in ten-thousandths of an inch, so that when working on reflection experiments this crystal can be backed out of position and placed in alignment again to that accuracy.

AXIS OF CRYSTAL B

As the axis of crystal B is the most complicated and essential part of the instrument it is shown in detail in Fig. 3.

The scale S_B is fixed to the original telescope-holding arm of the optical instrument and moves about with it. The lever arm L can be clamped to the shaft carrying the crystal table T_B by means of the clamp and screw C. The fine rotation of crystal B about its own axis is effected by this lever arm, 20.63 cm in length, and a tangent screw .05 cm in pitch. The large dial W has 500 graduations, hence one division on the dial moves the lever arm one ten-thousandth of a cm and rotates crystal B through one second of arc. This device for accurate slow motion is similar to that of Professor Bergen Davis. The adjust-

ment can be made with ease as the dial reads directly in seconds. The crystal B is first set to the approximately correct angle with respect to crystal A by means of the vernier V_B attached to the crystal-bearing shaft and reading on scale S_B. The lever arm and tangent screw producing the slow motion brings the exact setting for a line with very

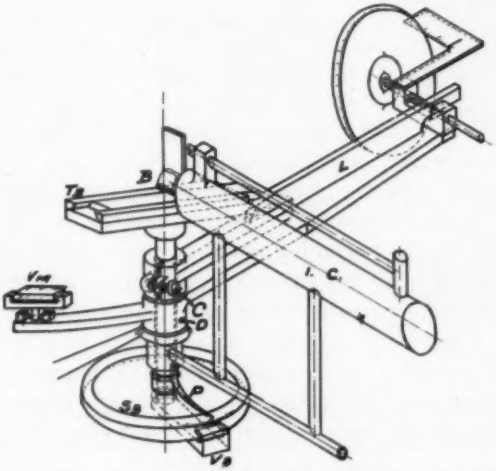


FIG. 3. *Mounting of axis of crystal B on double x-ray spectrometer.*

little searching. D is the arm from the central axis which supports the axis of B. This also carries the vernier V_M which reads the orientation of the axis of crystal B about the axis of crystal A, as well as carrying the support for the tangent screw and dial.

THE IONIZATION CHAMBER MOUNTING

The rod carrying the ionization chamber screws into a sleeve which is free to rotate about the axis of B. Its orientation with respect to crystal B is read by means of a pointer P on the scale S_B. Since the window of the chamber is comparatively large and the chamber close to crystal B, an accuracy of one degree is sufficient in this setting. There are two special rods, which connect to a long bearing around the A axis that support the combined weight of the B axis and the ionizaton chamber.

The chamber is a tube of Pyrex glass 40 cm long with nickel-plated gauze and rod electrodes inside. The chamber can be slipped out of the brass tube holder and completely removed without disturbing the rest of the instrument. The high potential connection; the guard-ring ground connections, and the valves for pumping and filling, project

horizontally from the end of the chamber. The thin copper wire which conducts the ionization current produced in the ionization chamber to the quadrant electrometer is effectively insulated and mechanically protected during movement of the ionization chamber by being supported in sulphur in the center of a brass tube which pivots over the crystals *B* and *A*.

THE ELECTROMETER

The electrometer is the Dolezalek type used heterostatically. A small variable potential can be applied to the insulated quadrants to test the sensitivity. The suspension is made conducting by sputtering. The electrometer and shielding cage are placed on a heavy block of cement hung by springs. Thus during readings our measurements are free from errors due to jarring of the electrometer. The tube supporting the wire carrying the ionization current enters through the center of the cement block. All the electrical connections are made by small springs to eliminate transmission of jars. The electrometer has a sensitivity of 4.5 meters on our scale at a distance of 2 meters. A lens system forms an image on the scale of a straight filament of an electric light after reflection from the electrometer mirror. The position of this image is read directly from the observer's seat near the spectrometer.

ELECTRICAL CONTROLS

The general plan of our electrical circuits is similar to that described by S. K. Allison and G. L. Clark,[5] with a few changes. The most important of these is the use of a Kirkpatrick[6] mercury resistance in the filament circuit. The filament circuit must be very accurately regulated during relative intensity measurements and with our instrument this regulation can be easily effected from the observer's seat by remote control of the Kirkpatrick resistance. The motor generator is run by a bank of cells with resistance controls in this circuit. The alternating current is rectified by kenetrons and smoothed by a capacity of .025 microfarads. The voltage, measured by an electrostatic voltmeter, is read directly on a calibrated scale by deflection of an image reflected from the mirror of the voltmeter. The variable resistances in the field circuit are placed near the observer's seat and allow control of the voltage across the tube, in such a manner that new settings may be made, the readings taken, and the voltage and current kept constant without the necessity of the observer moving about.

UNIVERSITY OF CALIFORNIA,
BERKELEY, CALIFORNIA,
MARCH 6, 1929.

[5] S. K. Allison and G. L. Clark, J.O.S.A. & R.S.I., *8*, p. 681; 1924.
[6] P. Kirkpatrick, J.O.S.A. & R.S.I., *7*, p. 195; 1923.

NOMOGRAMS FOR ROTATION PHOTOGRAPHS

By James B. Friauf

In the analysis of x-ray photographs taken by the rotating or oscillating crystal method, the quantities which are of primary interest are (1) the constant related to the identity distance in the crystallographic direction of the crystal which coincides with the axis of rotation, and (2) the $\sin^2\theta$ and the $\sin\theta$ values for the different reflections which occur on the photograph. These may be computed from the measurements made on the plate, or closely related quantities may be found from the chart published by Bernal[1] if the photograph is enlarged to the size which corresponds to a ten centimeter distance from crystal to plate. Each of these methods has certain disadvantages. The use of the chart requires a projection lantern for enlarging the photograph to the proper size unless it has been taken at a ten centimeter distance from the crystal, and it is possible that some of the weaker reflections may be overlooked when the photograph is projected on the network of lines in the chart. Calculation of the desired quantities, on the other hand, is highly inconvenient since the formulas which must be used are poorly adapted to slide rule computation. For these reasons it seemed desirable to prepare the nomograms which accompany this article, for the purpose of making the necessary calculations graphically when the distance from the crystal to the plate lies between 4.8 and 5.2. The use of these nomograms effects a very considerable saving of time, and the degree of accuracy obtained is sufficient for most purposes.

In preparing these nomograms it was assumed that the photograph is taken on a flat plate which is perpendicular to the incident beam of x-rays; that the axis of rotation of the crystal is likewise perpendicular to the incident beam of x-rays; and that the crystal is so oriented that some important crystallographic direction coincides with the axis of rotation. Let I be the identity distance for the crystallographic direction of the crystal which coincides with the axis of rotation. X-rays scattered at an angle φ with the axis of rotation by successive atoms on the lattice lines of the crystal which are parallel to the axis of rotation, will be in the proper phase for reinforcement if

$$n\lambda = I\cos\phi \qquad (1)$$

[1] J. D. Bernal, Proc. Roy. Soc., 113A, pp. 117–160; 1926. The ξ and ζ which are used by Bernal are related to the α and the $\sin^2\theta$ used in the present paper by the equations, $\xi^2 = 4\sin^2\theta - \alpha^2$ and $\zeta = \alpha$.

where n is an integral number and λ is the wave-length of the x-rays used.[2] All possible reflections consequently occur in the directions of the generators of a series of cones having their axes coincident with the axis of rotation, and semi-apex angles determined from equation (1) by giving different integral values to n. Only a few of the generators of these cones represent the direction of reflected x-ray beams because of the restrictions introduced by the two other similar conditions for interference.[3] All the spots on the plate corresponding to reflections for the same value of n lie on the same layer line which, in this case, has the form of a hyperbola since it is the intersection of a cone with a plane parallel to the axis of the cone. Three layer lines above and below the principal spectrum are shown in Fig. 1, which is a sketch of an oscillation photograph taken with the principal axis of a hexagonal crystal coincident with the vertical axis of rotation.

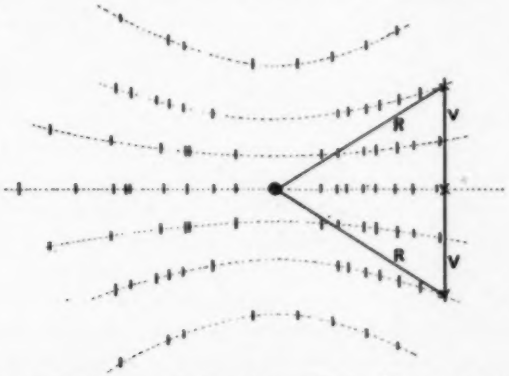


FIG. 1. *Sketch of an oscillation photograph from a hexagonal crystal.*

Equation (1) can be readily expressed in terms of the measurable distances, D, R, and V. D is the distance from the crystal to the plate. R and V are the distances which are to be measured on the plate and are shown in Fig. 1. R is the distance of the spot from the place where the incident beam of x-rays strikes the plate, and V is the distance of the spot from the principal spectrum. Since rotation photographs are symmetrical with respect to the principal spectrum, under the conditions which have been assumed, it is advantageous to measure $2V$ and divide by two. In terms of these distances

[2] Sommerfeld, Atomic Structure and Spectral Lines, translated from the third German edition by H. L. Brose, p. 112.
Ewald, Kristalle and Röntgenstrahlen, p. 42; Berlin, 1923.
[3] Sommerfeld, loc. cit., p. 115.
Ewald, loc. cit., p. 46.

$$\cos\phi = \frac{V}{(R^2+D^2)^{1/2}}$$

and equation (1) becomes

$$\frac{n\lambda}{I} = \frac{V}{(R^2+D^2)^{1/2}}. \tag{2}$$

The values for $V/\sqrt{R^2+D^2}$ are the same for all the spots on the same layer line, and the values for the different layer lines are integral multiples of λ/I. When this constant has been determined from a study of the photograph, the identity distance can be readily calculated.

The computation of the values of $V/\sqrt{R^2+D^2}$ for the different spots can be made graphically with the help of the nomogram in Fig. 2. If we use α to denote $n\lambda/I$, the equation to be represented is

$$\alpha = \frac{V}{(R^2+D^2)^{1/2}}. \tag{3}$$

While it is possible to construct a nomogram for the four variables α, V, R, and D, such a nomogram is so much less convenient to use than one for only three variables, that it seemed preferable to give D a fixed value to be determined by the dimensions of the apparatus used for taking the photograph and to provide some means of making the nomogram useful when D differs slightly from this value. A five centimeter distance from crystal to plate has been found convenient for many purposes, and the nomogram in Fig. 2 has consequently been calculated for the equation

$$\alpha = \frac{V}{(R^2+25)^{1/2}}. \tag{4}$$

To use the nomogram, a straight line is passed from the value of V on the V scale to the value of R on the R scale. This line intersects the α scale at the proper value for α. The straight line may be scratched on a piece of transparent celluloid, or a stretched thread may be used. Since the right hand side of equation (3) is a homogeneous expression of zero order in V, R, and D, the nomogram may be used whether these distances are measured in centimeters or in any other unit of length, if they are all measured in the same unit, and if $D=5$.

Since D may differ slightly, for accidental reasons, from the desired value, 5, it seemed desirable to incorporate some means of making

the nomogram applicable in this case. The method which has been adopted is based upon the consideration that α depends only upon the sum of the squares of R and D and not upon R and D separately.

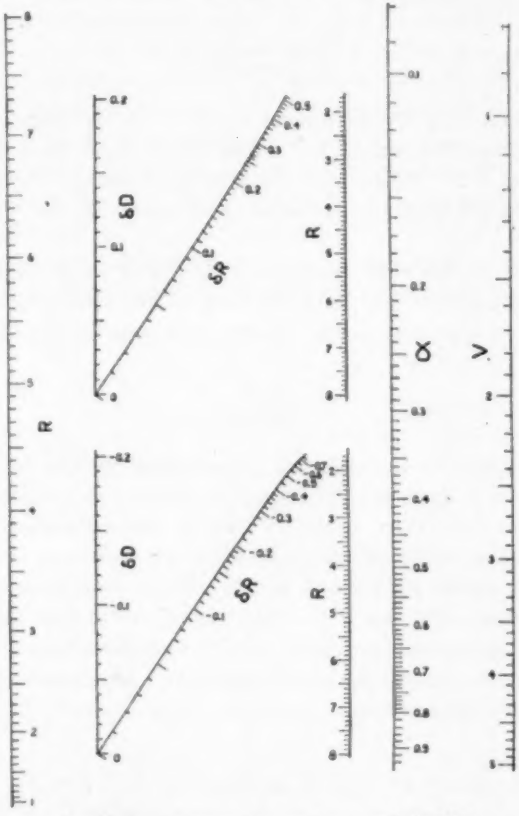


FIG. 2. *Nomogram for the equation* $\alpha = V/\sqrt{R^2+25}$

Hence the set of values V, R, D, will give the same value for α as V, R', D', if

$$R^2+D^2=R'^2+D'^2. \tag{5}$$

Let V and R be the measured values for a given spot on the plate and let D be the measured distance from the crystal to the plate. We shall also put $D=5+\delta D$ since it is assumed that the distance from the crystal to the plate is not greatly different from 5. Let $D'=5$ and $R'=R+\delta R$. Equation (5) now becomes

$$(\delta R)^2+2R\delta R-10\delta D=0 \qquad (6)$$

if the square of δD is neglected and this is permissible since δD is assumed to be a small quantity. The values of δR which satisfy equation (6) can be obtained from the two small nomograms between the α and the R scales of the main nomogram by running a straight line between R and δD and reading the intersection on the δR scale. The upper nomogram is to be used when δD is positive and the lower when δD is negative. δR is then added mentally to R to give R', and since D' is equal to 5, the main nomogram can now be used to obtain the value of α corresponding to V, R', D'. This value is equal to the value of α corresponding to the measured values of V, R, D by virtue of the preceding argument. For example, if $D=5.14$, $V=2.70$, and $R=4.30$, the value of δD is 0.14 and the value of δR obtained from the upper nomogram for this value of δD and $R=4.30$ is $+0.16$. R' is accordingly 4.46. A straight line passed from 4.46 on the R scale to 2.70 on the V scale cuts the α scale at 0.403. The computed value of α for $V=2.70$, $R=4.30$ and $D=5.14$ is 0.4029. In this way it is possible to extend the range of the nomogram to include all values of D between 4.8 and 5.2, and while the necessity of correcting the measured value of R when D is not equal to 5 makes the use of the nomogram somewhat less convenient in this case than when D is equal to 5, there is still a considerable saving of time.

The nomogram in Fig. 3 is for the $\sin^2\theta$ and the $\sin\theta$ values for the different reflections, where θ is the angle which occurs in the Bragg law of x-ray reflection. A straight line from R to D on the R and D scales cuts the middle scale at the appropriate values of $\sin^2\theta$ and $\sin\theta$. The $\sin\theta$ values may be used in connection with the charts of Hull and Davey.[4] These charts are for the interplanar distances, d, which are inversely proportional to the values of $\sin\theta$. The logarithms of d are hence equal to some constant minus the logarithms of $\sin\theta$. Thus if the logarithms of $\sin\theta$ are marked on a strip of paper with the help of the logarithmic scale at the bottom of the charts, and if the paper is then reversed end for end, the marks will give the logarithms of d (plus some constant) and can be compared with the charts in the usual way. This procedure is suitable for powder photographs but does not utilize the advantages of the rotation method to the full extent, since no use is made of the information furnished by the layer lines. For this reason it will generally be found preferable to use the

[4] Phys, Rev., *17*, pp. 549–570; 1921. General Electric Review, *25*, pp. 565–580; 1922.

$\sin^2\theta$ values and to utilize the simplifications which can be introduced by the knowledge of the identity distance in the direction about which the crystal rotates, as well as the further information which may be

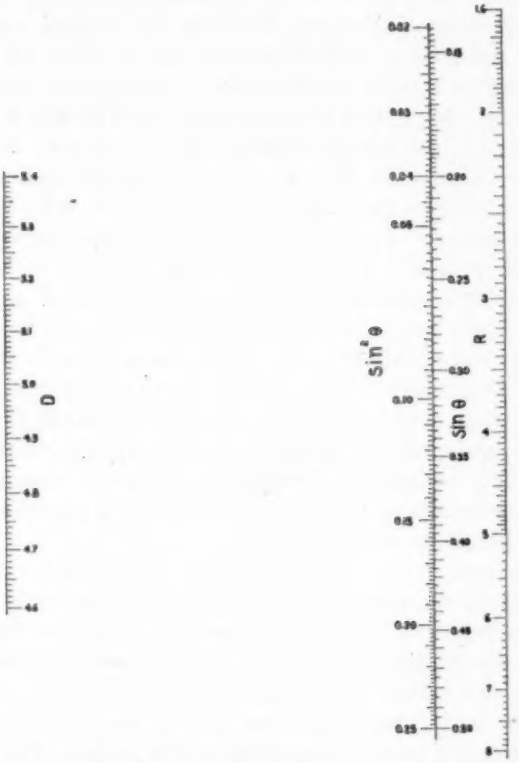


FIG. 3. *Nomogram for the equation* $R^2/D^2=1/(1-2\sin^2\theta)^2-1$

obtained from other photographs taken with the crystal rotating about different axes. The procedure to be followed has been explained in a number of articles[5] and need not be discussed here.

[5] Ewald, loc. cit., pp. 267–271.

Glocker, Materialprüfung mit Röntgenstrahlen, pp. 225–224; Berlin, 1927.

Polanyi and Weissenberg, Zs. fur Physik, *10*, pp. 44–53, 1922.

Bernal, loc. cit. This article is probably the most comprehensive account of the rotation method which has yet been published in English. It contains a description of a graphical construction based on the reciprocal lattice which is useful for determining which crystal planes reach a position to reflect a beam of x-rays.

It is evident that the usefulness of the nomograms is not restricted to rotation photographs. The nomogram in Fig. 3 can be used for the determination of the $\sin^2\theta$ and the $\sin\theta$ values corresponding to the different rings in a powder photograph, provided, of course, that the photograph is taken on a plate, and that the distance from crystal to plate is in the range of values given on the D scale. Both nomograms may be used in the study of fiber diagrams when the fiber axis is perpendicular to the incident beam of x-rays.

Although the use of the nomograms requires no knowledge of the way in which they have been constructed, it seems desirable to give the equations of the scales for the benefit of those who may wish to prepare similar nomograms for a different range of values of D. Let x_1, y_1, be the Cartesian co-ordinates of a point on the R scale of the nomogram in Fig. 2, x_2, y_2, the co-ordinates of a point on the α scale, and x_3, y_3, the co-ordinates of a point on the V scale. The equations of the three scales are

$$\begin{aligned} x_1 &= 0 \\ y_1 &= \frac{\log (R^2+D^2) - 1.44}{0.017} \\ x_2 &= \frac{540}{35.5} \\ y_2 &= \frac{-0.02 - \log \alpha}{0.0355} \\ x_3 &= 20 \\ y_3 &= \frac{0.7 - \log V}{0.027} . \end{aligned} \tag{7}$$

The condition that three points lie on the same straight line is

$$\frac{y_3 - y_1}{x_3 - x_1} = \frac{y_2 - y_1}{x_2 - x_1} \tag{8}$$

If the values for the co-ordinates of the points on the three scales as given by the equations (7) are introduced in equation (8) the result is found to be

$$\log \alpha = \log V - \tfrac{1}{2} \log (R^2+D^2)$$

and consequently the values of α, V, and R which lie on the same straight line are such as to satisfy equation (3).

The equations for the scales of the subsidiary nomograms in Fig 2 are

$$\begin{aligned} x_1 &= 0 \\ y_1 &= 60\delta D \\ x_2 &= \frac{63\delta R}{6.3\delta R+1} \\ y_2 &= \frac{96\delta R+6(\delta R)^2}{6.3\delta R+1} \\ x_3 &= 10 \\ y_3 &= \frac{16-2R}{1.05} \end{aligned} \tag{9}$$

when δD is positive, and

$$\begin{aligned} x_1 &= 0 \\ y_1 &= -60\delta D \\ x_2 &= \frac{63\delta R}{6.3\delta R-1} \\ y_2 &= \frac{96\delta R+6(\delta R)^2}{6.3\delta R-1} \\ x_3 &= 10 \\ y_3 &= \frac{16-2R}{1.05} \end{aligned} \tag{10}$$

when δD is negative. Insertion of these values in equation (8) shows that any straight line cuts the three scales at values of the variables which satisfy equation (6).

In the nomogram shown in Fig. 3 it is desired to find the value of $\sin^2\theta$ corresponding to a given R and D, where

$$\tan 2\theta = \frac{R}{D}. \tag{11}$$

Expressed in terms of $\sin^2\theta$ this relation between the three variables becomes

$$\frac{R^2}{D^2} = \frac{1}{(1-2\sin^2\theta)^2} - 1 \tag{12}$$

and this is accordingly the equation to be represented by the nomogram. The equations of the scales are

$$
\begin{aligned}
x_1 &= 0 \\
y_1 &= 250 \log D - 160 \\
x_2 &= \frac{350}{20.5} \\
y_2 &= \frac{195}{20.5} - \frac{375}{20.5} \log \left(\frac{1}{(1-2\sin^2\theta)^2} - 1 \right) \qquad (13) \\
x_3 &= 20 \\
y_3 &= \frac{337.5}{8.75} - \frac{375}{8.75} \log R.
\end{aligned}
$$

After the $\sin^2\theta$ scale has been constructed, it is a simple matter to mark the corresponding values of $\sin\theta$ at their appropriate places.

In case it is desired to prepare similar nomograms for different ranges of the variables, it will probably be found that the particular values given to the numerical constants in the equations of the scales for the nomograms, equations (7), (9), (10) and (13), are unsuitable. A nomogram constructed with these values for the constants will, it is true, give the correct results for all values of the variables, but the parts of the scales which are to be used may be separated by a considerable distance in the direction of the y axis, and certain of the scales may be very much compressed as compared to the others. These inconveniences can generally be removed by the application of a projective transformation[6] which can be used to transform four arbitrarily chosen points on the nomogram to any desired positions on the transformed nomogram. By a proper choice of the transformation it will generally be found possible to effect a suitable arrangement of the scales on the transformed nomogram.

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CARNEGIE INSTITUTE OF TECHNOLOGY, PITTSBURGH, PA.
FEBRUARY 13, 1929.

[6] Hewes and Seward, The Design of Diagrams for Engineering Formulas and the Theory of Nomography, pp. 105–108; New York, 1923.
Soreau, Nomographie ou Traité des Abaques, *1*, pp. 155–161; Paris, 1921.

SOME USES OF ALTERNATING CURRENT SUPPLY

By Paul F. Gaehr

ABSTRACT

The alternating current supply is a convenient source of current in frequency measurements and comparisons, unless high degree of constancy is desired. An ac arc also is a fairly satisfactory intermittent source of light. A number of experiments are described, making use of these facts:

(1) The motion of a tuning fork and explanation of beats.
(2) Waves on liquids can be shown, including the case of beats.
(3) Slight phase changes may be shown when a heavy motor is connected to the line.
(4) An audio-oscillator may be calibrated.
(5) Reaction of closely and loosely coupled circuits may be mechanically demonstrated; and an explanation found for the difficulties sometimes encountered in Melde's Experiment. Also, there are explained two useful theorems in connection with Lissajou figures.

In attempting to explain to my classes in a simple manner some of the interesting phenomena of vibratory motion, I have been hampered by a dearth of the necessary apparatus. However, I have an ac supply of fairly constant frequency (62.7 to 62.8), a Phoneloscope, and two large tuning forks. The forks are electrically driven (like a door-bell), can be adjusted over a wide range of frequency, and the electromagnet can be moved; each fork has a mirror on one prong, mounted with its plane normal to the prongs. I have also a large fork of about 64, and another of about twice the ac frequency. With this outfit, I have been able to show a number of interesting experiments, which I thought it worth while to publish. In addition to that, I hope to be able to calibrate definitely a number of oscillators in my laboratory by methods outlined in two excellent articles in this journal;[1] one always needs to start with an accurately known and absolutely fixed frequency.

Before describing the experiments, I wish to describe one use of the ac arc to show persistence of vision. Place into a lantern a glass plate on which there is a letter or word, and focus the lantern on a portable screen placed in an open door-way. Remove the screen, and wave a stick rapidly across the plane of the image. Altho only a portion of the image may be seen at a time, still the word can be read.

I. THE MOTION OF A TUNING FORK

Arrange a fork to twice the frequency of the ac, and hold it in the field of a lantern supplied with an ac arc. If the fork is slightly detuned, the image will move very slowly. At the same time the class can hear

[1] J.O.S.A. & R.S.I., *14*, pp. 263–285; and *15*, pp. 25ff.

beats between the fork and the sound of the arc, the beats having the same frequency as the fork *image* on the screen. To hear the beats, the fork must be held in a standard, and not in the hand.

Again arrange the fork in unison with the sound of the arc. If the fork is struck very hard, so as to have a large amplitude, it will be seen to be out of tune until the amplitude has died down. This demonstrates clearly the dependence of fork frequency on amplitude. This point can also be demonstrated by a method described further on.

If the properly tuned fork is held in the field of the lantern while someone connects a large motor to the line, it will be evident that the ac has been slightly "detained," because the prongs will be seen in a different phase of their motion.

II. WAVE MOTION EXPERIMENTS

Waves may be made on a liquid by means of either the fork of ac frequency or by the fork of double frequency, and the liquid illuminated by an ac arc. The waves will appear stationary. If the fork be made slightly *higher* in pitch, waves will appear to progress very slowly.

If both prongs of the fork be in the liquid, one gets the usual interference pattern from two similar sources. But one may use two forks—one of ac frequency and the other slightly higher or lower; dipping one prong of each into the liquid will show the interference pattern sweeping across the field, illustrating what happens when one hears beats.

III. CALIBRATION OF A FORK

One of the heavy, electrically driven forks was set up opposite a Phoneloscope, the fork vibrating horizontally. A beam of light was directed towards the mirror on the end of the fork, thence into the Phoneloscope, and thence to the screen. The phoneloscope was connected to the ac supply through a transformer. The fork was then adjusted, by means of the Lissajou figure, to unison with the ac. In this arrangement we can again show the dependence of fork frequency upon amplitude by obserbing the change of the Lissajou figure when the driving current is increased. Shifts in the phase of the ac supply are similarly shown.

The Phoneloscope may now be disconnected from the ac supply, and connected in parallel with the driving coil of other electrically driven forks, and by the resulting Lissajou figure, these other forks may be calibrated. Also, by connecting the Phoneloscope to an Audio Oscillator, we can obtain a number of calibration points up to about 500.

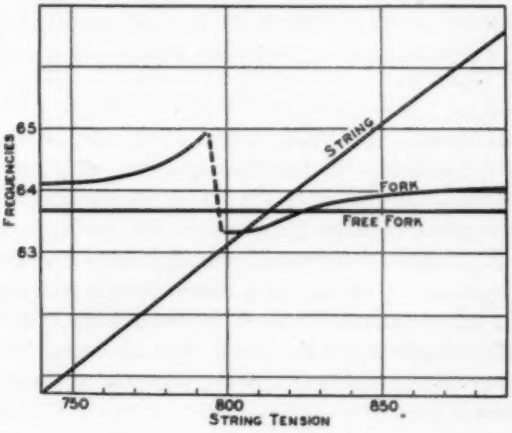
In this work I have made use of two properties of Lissajou curves that do not appear to be generally known: 1) If the figure is stationary, the frequency ratio may be easily obtained. Draw a vertical line on either side of the pattern, and a horizontal line at either top or bottom. To every tangency assign the value 2, and to a line starting in a corner, assign the value 1; then find the horizontal and vertical sums. Their ratio is the ratio of vertical to horizontal frequency. 2) If the frequency ratio is very nearly $n_v/n_h = V/H$, and the figure repeats itself once in t seconds, then

$$\frac{n_v}{V} - \frac{n_h}{H} = \frac{1}{VHt}.$$

A knowledge of these two facts greatly enlarges the number of frequencies that may be determined from a single standard.

IV. MELDE'S EXPERIMENT AND COUPLED OSCILLATORS

With the Phoneloscope fed from the ac supply, and the large fork somewhat faster than unison, Melde's Experiment was performed in the usual manner, by attaching a string to one of the prongs. The Lissajou curve, by its width showed how the oscillator (fork) was



robbed of energy; and by its rate of repetition, it showed the effect of resonance on its frequency. The figure herewith shows the variation of resonator (string) frequency with attached load, and also the variation of oscillator (fork) frequency. The horizontal line is drawn to show the frequency of the fork when the string is removed.

To show what happens when the coupling is reduced, the string was then attached to the base of the fork, and stretched in a direction at right angles to the prongs. The coupling was so slight that resonance had to be detected by means of a low power microscope. The fork frequency was changed by only .01 cycle.

V. SELF AND MUTUAL INDUCTANCE

Let the deflecting plates or coils of a Braun Tube or W. E. Oscillograph be connected to an ac supply. Into one of the branches connect a coil *C*, of quite a few turns; into the other branch a similar coil may be connected, or the ohmic resistance of *C* may be balanced by a pure resistance. The Lissajou figure is a straight line, or nearly so.

Insertion of an iron core (preferably laminated) into *C* will retard and diminish the current in that branch. The figure changes to an ellipse; and the motion due to the current in the *C* branch is diminished.

If the coil has also a low resistance secondary, and this is short-circuited, the secondary current tends to neutralize the self-induced component of the primary, and the figure tends to change back to a straight line.

An interesting variation of this experiment is to use two-phase current for the two magnetic or electric fields. In this case one obtains a circle in place of the straight line.

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ON THE ELIMINATION OF ERRORS WHEN WIRE SCREENS ARE USED AS NEUTRAL FILTERS FOR PHOTOGRAPHIC PHOTOMETRY

By George R. Harrison

When photographic photometry is used in spectral work, one of the principal problems is the selection of a suitable means of reducing light intensities by a known amount. To simplify matters, it is generally desirable to reduce all wave lengths proportionately, which necessitates the use of some "neutral" means of weakening a collimated beam of light. One of the most satisfactory methods is to use screens of blackened wire mesh, which furnish a large number of small apertures uniformly distributed across the beam, thus eliminating the necessity of having this beam of uniform intensity over its cross section.

Ham, Fehr, and Bitner[1] appear to have been the first to use screens for this purpose. Since their work several papers[2] have appeared discussing the use of screens, and suggesting different methods of their calibration. There has been some question as to whether the screens are truly neutral, but experiments by Lansberg[3] indicated that they could be considered so to within one or two per cent over the range 2000-5000 angstroms. W. Wein[4] discusses the fact that when low transmission screens are used the image formed by the light passing through them is very diffuse, and several writers have mentioned that diffraction effects might cause errors in the use of such screens. Black cloth has been used by some workers instead of wire netting.

During the past few years the writer has constructed a number of sets of such screens for photometric purposes, and has calibrated and used them in a variety of ways. Various sources of error have been found from time to time when results obtained with them were checked in other ways, and the present note contains a discussion of these errors and the means by which they can be eliminated.

CONSTRUCTION OF SCREEN FILTERS

For general photographic photometry in the infrared, visible, and ultraviolet, it is desirable to have a set of screens which will transmit

[1] Ham, Fehr, and Bitner, Jour. Franklin Inst., *178*, p. 299; 1924.

[2] Winther, ZS. f. wiss. Phot., *22*, p. 125; 1923; ibid, *25*, p. 230; 1928; Robertson, this journal, *7*, p. 983; 1923; Harrison and Hesthal, this journal, *8*, p. 471; 1924.

[3] Landsberg, ZS. f. Phys., *46*, p. 106; 1927.

[4] W. Wien, Ann. d. Phys., *73*, p. 499; 1924.

from 100 per cent of the light down to 1 per cent, in, say, 10 fairly evenly spaced steps.[5] These will give a satisfactory number of points for plotting accurate characteristic curves over a 100-fold range of intensities, which, in the case of photographic plates of nearly unit contrast, covers the whole of the most useful density range of the plate, with some overlap for variations with wave length of emulsion sensitivity and brightness of source.

As the screens can be used in combination, it is desirable to keep the total number of different screens down to a minimum. It is also desirable to use as few screens together as possible, and for this reason the policy has been adopted of never using more than two screens at once where they must be calibrated separately. In the sets prepared by the writer four screens have been provided, and by using these in pairs the desired intensity range has been satisfactorily covered. In Fig. 1 are shown contact prints of the meshes of these screens.

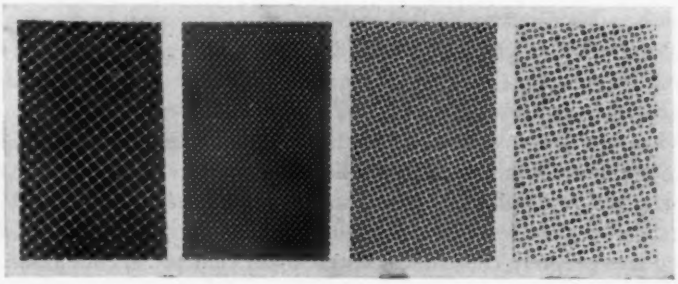

FIG. 1. *Contact prints of the screen patterns used in a typical set of neutral screens. Transmission factors: #1, 69.7%; #2, 40.9%; #3, 21.8%; #4, 6.76%. The screens are used in the following order: None, #1, #2, #1 and #2, #3, #1 and #3, #2 and #3, #4, #1 and #4, #2 and #4, #3 and #4. This gives 11 points covering the intensity range 100% to 1.47%.*

Screens Nos. 1 and 2 are single, while No. 3 contains two pieces of wire gauze clamped securely together, and No. 4 contains three. Provided the screens are carefully mounted there seems to be no difficulty due to changing transmission in these multiple units. The mounting finally adopted consists of a brass ring of 10 cm internal diameter, with edge 2 cm broad, and 8 mm thick along the axis of the cylinder. The inside of this ring is recessed to give a flat bearing for the edge of the wire netting, which can be clamped in place by screw-

[5] See, for example, Harrison, Phys. Rev., *24*, p. 466; 1924.

ing a collar down against it on the inside of the threaded ring. For some time burning-off black was used to darken the screens, but this tends to produce a slight unevenness in thickness of the wires forming the mesh, and a better method seems to be to oxidize the brass or copper wire by heating it uniformly in a flame. While the screens are still hot they are placed between two hot disks of brass, fitted into the cold ring, and the collar is clamped down into place on their edges. When cool the resulting contraction gives a very tight flat surface, and the thick edge of the ring protects the wire mesh from mechanical disturbances. When not in use the screens are kept in a dust-proof container, and they are otherwise treated like valuable optical parts. Sets constructed in the way outlined above have been in use for several years, and repeated calibration shows no variation in their transmission values.

In the multiple screens it is desirable to have as uniform a pattern as possible, with the wave effects (moiré effect) of short length. Two single screens are put together, and rotated with respect to one another until the resulting pattern has the finest structure. In 3 and 4 of Fig. 1 it will be seen that the "beat frequencies" of the pattern are almost as great as the "wave frequencies."

When two screens, single or multiple, are to be used together, it is of course necessary that they be kept in irregular motion relative to one another to get an average transmission value, since their combined transmission will vary with the relative position of their meshes. Using two properly chosen screens of 50 per cent transmission and the same mesh, it is conceivable that their combined transmission might vary from 50 per cent to zero, depending upon their relative positions. For this reason it is desirable that no two screens in any set should have the same mesh. Also they should be so chosen that the variations in light intensity when they are moved relative to one another are a minimum, to reduce the photographic intermittency effect, discussed below.

Several methods of moving the screens have been tried. Originally the writer hung them as pendulums of different periods and amplitudes, connecting them together with rubber bands. The next step was to provide a pair of horizontal rotating shafts containing eccentric collars, the screens riding between two collars and rotating while they moved horizontally and vertically relative to one another. The rotation was found to be very objectionable, as it introduced an abnormally large variation in the total transmission of the screens. Finally a

machine was constructed which moves the screens with uniform circular motion of about one cm amplitude without rotating them.

Two eccentric collars are placed on a shaft which is turned at about 120 rpm by an electric motor, and from these project two arms which contain short slots at points about two-thirds of their length above the shaft. A pin through these slots holds the arms while they slide up and down. On top of each arm is placed a quarter circle of brass, recessed to hold a screen rim loosely. This contains a pin which fits into a hole in the screen rim when it is inserted in place. The screens are put into this rocking machine singly or in pairs when they are to be used, and at all other times are kept in a closed box.

It is, of course, desirable to use as many of the apertures in the screens as possible, and they should therefore be put in some portion of the light beam which has a large cross-section. This generally means near the lens used to focus the beam of light on the entrance slit of a spectrograph. Inasmuch, however, as the spectrograph generally controls the aperture of the system, it should be remembered that often only a very small portion of this lens is being used, especially if it is close to the slit. For this reason, as well as others, it is desirable to have this focusing lens at some distance from the slit, so as to use as much of its aperture as possible.

It is also desirable that the screens shall be so placed that they cause no unevenness in an image of the slit in the focal plane of the spectrograph. With a stigmatic mounting, this condition is easy to fulfill, but with most of the usual types of grating mounting, where several portions of the spectrum can be photographed at once (as in the Paschen mounting) the astigmatism of the system will often bring the screens into vertical focus at a certain point in the focal plane of the spectrograph. Placing the screens on the opposite side of the lens will frequently move this position of focus to some part of the focal plane not in use. If care is not taken in this regard, the screen motion may introduce small intermittency errors. Spectrograms taken with the screens at rest make evident any unevenness in the spectral images.

When the two screens move relative to one another, moiré patterns are produced which cause variations in the total transmitted light. These variations can be reduced to a minimum by always using the screens with their wires at such relative angles that the patterns change only slightly when the screens move. This is taken care of, in the screens used by the writer, by the hole in the edge of the screen mounting, which fits a pin in the oscillating machine. In this way the screens are always held in the same relative position when in use.

ERRORS DUE TO DIFFRACTION

While numerous precautions have been listed above, it is doutful if errors greater than five per cent would occur if most of the points mentioned were neglected. As will be seen below, the intermittency errors are all second or third order effects. A far more important source of error, and one often overlooked in practice, though realized theoretically, is that due to diffraction. A number of experiments were performed by the writer to find the magnitude of this effect under various conditions. The results to be discussed were obtained when the conditions were deliberately made as bad as possible in this regard.

The image of an incandescent lamp filament was focused on the slit of a spectrograph in the usual way, the slit being about one mm

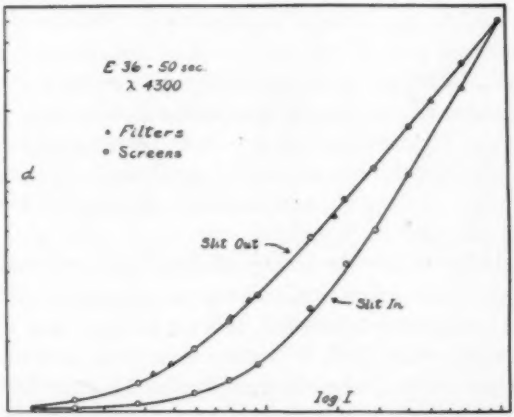

FIG. 2. *Calibration curves showing the errors which can enter when diffraction effects are not allowed for. The upper curve contains points obtained with calibrated glass filters (marked with triangles) and with wire screens correctly used. The lower curve was obtained with the same screens incorrectly used.*

wide and the image just filling it. The screens, which had been calibrated by the methods discussed below, were then inserted in sequence, and a set of calibration exposures for λ 4350 was thus impressed on the plate. These later were found to give the curve marked "Slit in" in Fig. 2. The important point to note is that this is a perfectly good-looking characteristic curve, which from its appearance would not lead one to suspect errors. Yet intensity ratios taken from this curve could be as much as 100 per cent above their true values.

After taking the set of exposures with slit in, the slit was removed and an exactly similar set of exposures was taken. These were later found to

give the calibration curve marked "Slit out." This is again a regular appearing characteristic curve, and is the correct one, as is shown by its agreement with the characteristic curve determined with glass filters whose transmission values had been measured for λ 4350 with a spectroradiometer. It is evident that much more light affects the plate through a given screen when the slit is removed than when it is in place.

The reason for this is not far to seek when one observes the image of the filament in the plane of the slit. While it is quite sharp when no screen is in the beam, as soon as one is inserted it becomes blurred, and if the image exactly covered the slit originally, a portion of the light is now thrown to each side and does not enter the spectrograph.

In Fig. 3 are shown typical images of the same source with various screens inserted in the beam. (a) is with no screen; (b) is with screen

a b c d

FIG. 3. *Photographs of the image of a beam of light focused on the entrance slit of a spectrograph. a, image without screen, b, image with screen #1 inserted in beam, wires parallel and perpendicular to length of image. c, ditto, with wires at 45°. d, Screen #2 inserted in beam, wires parallel and perpendicular to image.*

No. 1 arranged with its wires running parallel and perpendicular to the slit; (c) is with the wires running at 45°; (d) is with screen No. 2, wires parallel and perpendicular. The various orders produced by the grating action of the screens are clearly visible.

The example taken is obviously an extreme one, and in cases where the slit is more than four times the width of the light beam, or the light beam is very broad compared to the diffraction broadening and to the slit, the effect is probably negligible. There is every reason to believe, however, that when screens are used in the ordinary manner errors of from 5 to 15 per cent can and do creep in entirely unobserved.

One would naturally expect that different screen combinations would produce different proportional amounts of diffraction, and that consequently the resulting characteristic curve would not be smooth.

This is to a slight extent true, but the lower curve of Fig. 2 shows that the screens are similar enough that the light lost to the sides of the slit is closely proportional to the weakening power of the screen. As the screens used were not definitely chosen to make this true, and as a similar effect has been observed with other sets of screens, it is probably so nearly true generally that irregularity of the curves cannot be trusted to indicate presence of the effect.

The commonest method of testing for accuracy of a characteristic curve is to repeat the curve using the same light-weakeners, but with a lower or higher intensity of light. A new curve should then be obtained which is accurately parallel to the original curve. This was done on the plates from which the curves of Fig. 2 were taken, and the resulting curves were parallel in all cases. This indicated that the diffraction effects were proportional to the weakening powers of the screens producing them, and the method is therefore worthless for testing the accuracy of a calibration curve obtained with screens.

While the error discussed above is probably by far the greatest one, a second order effect appears with it which cannot be neglected. If the diffraction effects are not negligible, the diffraction will produce a departure from neutrality in the screen, since a greater proportion of the light of longer wave lengths will be lost in a given case. The writer believes that cases where screens have appeared to depart from exact neutrality can be ascribed to this cause; exhaustive tests on screens used in such a way that diffraction errors are carefully excluded show exact neutrality from the far infrared to the extreme ultraviolet.

USE OF THE SCREENS TO ELIMINATE DIFFRACTION ERRORS

While diffraction effects can produce large errors if neglected, they are extremely easy to eliminate. The writer has made a practice of removing the slit of the spectrograph while calibrating with a continuous source, whenever possible. This can be done with a large grating instrument without inconvenience, provided certain arrangements are made to avoid extraneous light and to limit the beam of light where it falls on the plate.[6] Where this is not possible, a very broad image can generally be used on the slit when the diffraction effects will be so small as to be negligible. If this cannot be done, it is only necessary to calibrate the screens in position for use, the thermopile or photoelectric cell being placed behind the spectrograph slit so that the diffracted light fails to be measured. The screen transmissions will then

[6] Harrison, this journal, *17*, p. 389; 1928.

be found to be smaller than when calibrated in the ordinary way, the diffraction errors being exactly compensated. These transmission values could not, of course, be used safely with different source-lens-slit systems.

ERRORS DUE TO INTERMITTENCY EFFECT

While calibration of the screens in position as they are to be used, or use of such a wide beam that diffraction effects are relatively unimportant, or allowing all diffracted light to enter the slit (in the case of continuous spectra) will eliminate most errors, those due to the failure of the photographic plate to properly integrate the light falling on it will not be so eliminated. As mentioned above, it is therefore desirable on general principles to keep variations in transmitted intensity to a minimum.

In order to determine the conditions affecting the intermittency failure of the photographic emulsion, assuming a certain basic unavoidable variation in screen transmission, Weinland[7] in this laboratory made a careful investigation of the intermittency effect in plates ordinarily used for photographic photometry. Under the conditions generally used, an intermittent exposure produces less density than an equivalent continuous exposure. Also the intermittency effect increases with a decrease in the intensity of the light, which makes its effect worse under the conditions in which it is most apt to enter, i. e. with small screen transmissions.

It is desirable to separate the intermittency error into two parts, that which affects the apparent contrast of the plate, and that which affects its sensitivity. Where the screens are used only in determining the shape of the characteristic curves of an emulsion at different wave lengths, as is generally the case, we are concerned only with the first. Often, however, as where the mercury arc under high energy input is used as a source in the ultraviolet, it is desirable to use the screens as neutral weakeners, and both effects may enter.

Weinland found the greatest intermittency effect with slow plates and at long wave lengths. It should be remembered, however, that the slow plates had greater contrast, and this was greatest at longer wave lengths, so it is probable that the variation is only apparent in the density measurements, and practically disappears when these are reduced to intensities. We may thus assume that all intermittency errors will be independent of wave length and of the type of plate used, to a first approximation.

[7] Weinland, this journal, *15*, p. 337; 1927.

Weinland also found that when the individual flash was very short the intermittency effect was only slightly dependent upon the frequenecy of flash, but that the ratio of rest period to flash period is very important, a short flash followed by a long rest period producing the greatest intermittency error. Finally, he showed that a pre-exposure to a constant intensity greatly reduced the departure from normal when a succeeding intermittent exposure was made on the same plate.

In order to determine the magnitude of the light variation to be expected, the instantaneous transmissions of the screens in pairs were measured with a photoelectric cell, placed in the central image of a 21 ft. grating. The whole experimental set-up, including the screens, was exactly as when used for photographic photometry, the photoelectric cell at the central image taking the place of the photographic plate at the desired wave length. The oscillating machine was rotated very slowly so that the galvanometer lag would not mask variations in light intensity. It was found that with screens No. 1 and No. 2 together the variation in light intensity was $\pm$ 1.1 per cent of the total intensity, while the worse case, screens No. 3 and No. 4 together, showed $\pm$ 3.5 per cent variation. When no care was taken with the screens to so arrange them that the light variation was kept small, the maximum variation observed was not much over $\pm$ 5 per cent. A larger variation could be expected when diffraction effects which varied with screen position were entering, but these, of course, must be eliminated in any case.

Correlating these values with the data of Weinland's paper, we conclude that the errors due to intermittency failure will be vanishingly small. If the light intensity fell to zero between flashes, with a definite rest period, we could expect errors of appreciable magnitude (5 per cent - 20 per cent) to enter. But even a 10 per cent "ripple" would make less than 1 per cent error, and would change neither the slope nor the position of the characteristic curve appreciably.

CALIBRATION OF SCREENS

The great advantage of the screen method lies in the fact that the screens can be calibrated with white light or strong light of any color, and being neutral, they will have the same transmission values at all wave lengths. Three methods of calibration have been adopted by the writer, and their results are found to agree very closely.

Method 1. The greatly magnified image of the incandescent filament of a lamp run from storage batteries is thrown on a thermopile, thermocouple, or photoelectric cell connected to a sensitive galvano-

meter. The screen to be measured is placed in a wide part of the light beam, and the ratio of galvanometer deflections with screen in and out gives the transmission factor. (The thermopile-galvanometer or other combination must, of course, have been previously calibrated for linearity of response, preferably by means of the inverse square law.) The thermopile should preferably cover only a portion of the light beam falling on it. The transmission factor of the screen should be the same when it is placed in any part of the beam. If it is not the cause is generally diffraction effects or actual screen unevenness.

Method 2. Light from a high power quartz mercury arc run from a constant electrical supply is sent through a quartz prism monochromator and is then partially brought to a focus on a quartz sodium-hydride photoelectric cell for the ultraviolet, or a glass potassium-hydride cell for the visible. Light of a particular wave length is chosen, and the screen is inserted in the beam as in method 1. In this way the screens can be calibrated at individual wave lengths, and diffraction effects do not enter, since the entire blurred spot of light still affects the cell. Screen transmission factors taken in this way from 2500 A to 4300 A agreed with those obtained by method 1 for white light, and with those obtained by using filters in method 1 which transmitted only the infrared or various colors singly.

Method 3. This has been discussed somewhat above. The screens are calibrated by placing them in the beam in which they are to be used, the photoelectric cell or other radiometer being placed behind the spectrograph slit. With a large grating it can conveniently be placed in the central image. Screen transmission factors obtained in this way will generally be lower than the true values obtained by methods 1 and 2, and can be used only for the set-up in which calibrated. As a general rule, it seems better to use method 1 or 2, being careful that diffraction effects are not allowed to enter when the screens are used.

The final test of the screen method must, of course, lie in its agreement with other methods accepted as accurate. Where filters have been calibrated for a given wave length, and are used in the position of calibration so that refraction errors cannot enter, no intermittency effects or diffraction effects need be feared. Repeated comparison between calibration curves obtained with filters and with screens have shown that they agreed perfectly when the precautions listed above were taken, except that the screen curves were slightly more regular. This is undoubtedly due to the fact that it is easier to make a uniform screen than a uniform filter, and it is also easier to keep it clean and free from scratches and grease.

The great advantage of the filter lies in the fact that it can be fashioned into a wedge, step-filter, or other type of "light weakener" which gives a number of calibration points with a single exposure and thus saves time *at a given wave length*. When long exposures must be taken this is very desirable. However, with exposures of a few minutes or under the screens, they save time, since they are accurately neutral and need be calibrated at only one wave length. In fact, the writer believes that the easiest way to calibrate a step-filter at a number of wave lengths is to do it by means of photographic photometry, using screens as a standard.

DEPARTMENT OF PHYSICS,
STANFORD UNIVERSITY,
PALO ALTO, CALIFORNIA.
FEBRUARY 26, 1929.

Donnees numerique de Photographie. By W. Clark. pp. 36. Price: bound, 36 fr; paper, 20 fr.

Donnees numerique de Spectroscopie. (Emission spectra; absorption spectra; Zeeman effect). By M. Bruninghaus. pp. 363 Price: bound 180 fr.; cloth, 160 fr.

Both volumes are reprinted from the Annual Tables of Constants and Numerical Data (for 1923–1924). Gauthiers-Villars & Co., 55 Quai des Grands-Augustins, Paris (VI°).

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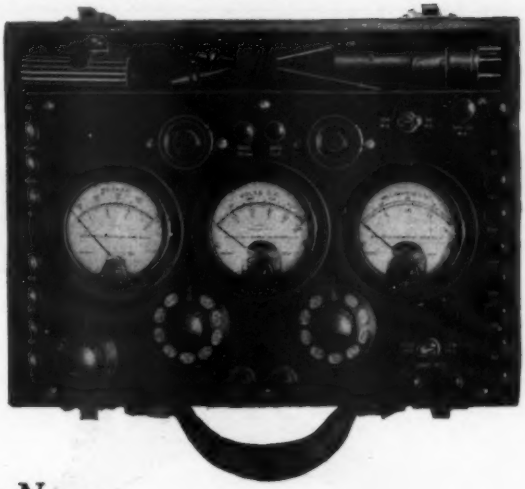

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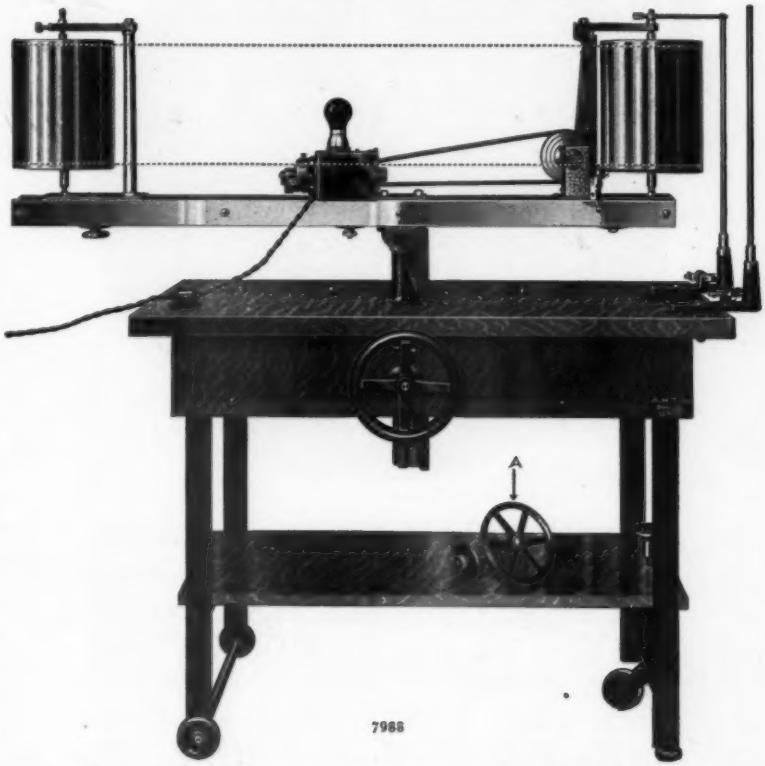

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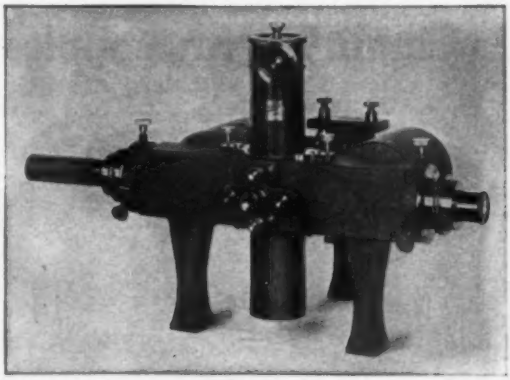

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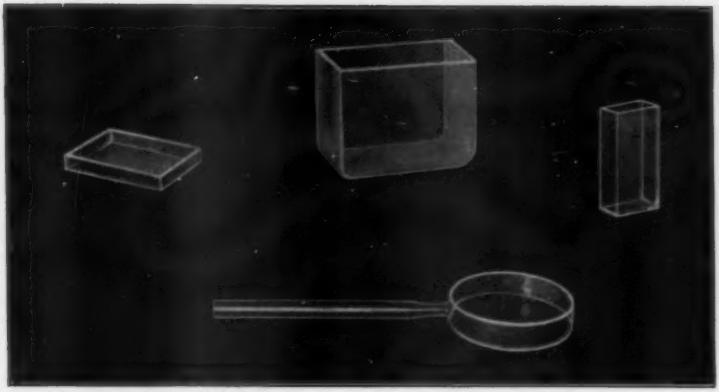

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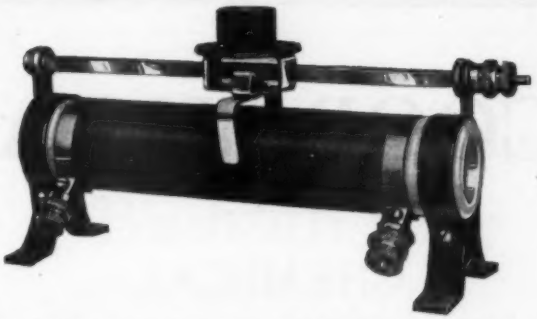

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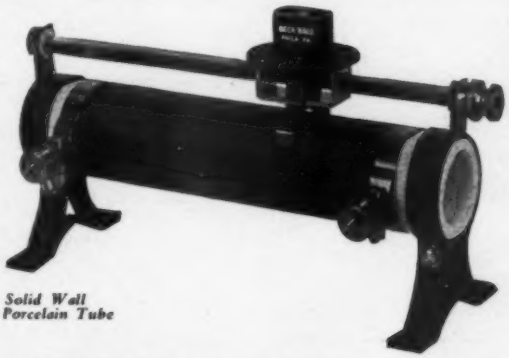

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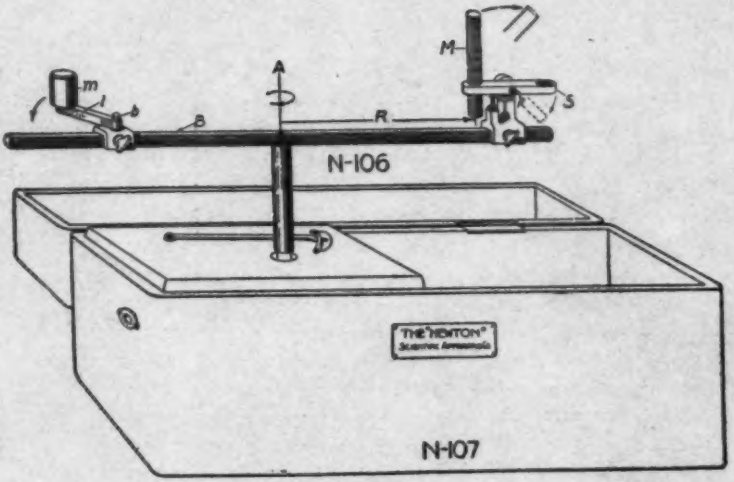

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